Proceedings of the 7th international conference on disability, virtual reality and associated technologies, with ArtAbilitation (ICDVRAT 2008)

The 7th International Conference on

Disability, Virtual Reality and Associated Technologies

with

ArtAbilitation

Proceedings

Edited by:

Paul Sharkey
Pedro Lopes-dos-Santos
Patrice L (Tamar) Weiss
Tony Brooks

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ICDVRAT 2008

with ArtAbilitation 2008

The papers appearing in this book comprise the proceedings of the 7th International Conference on Disability, Virtual Reality and Associated Technologies, together with ArtAbilitation 2008, held on the 8th, 9th, and 10th of September, 2008 in the Maia Forum, Maia, Portugal, with a further special session on the 11th of September, 2008 in Casa da Música, Porto, Portugal. The papers presented reflect the authors' opinions and are published as presented and without change (formatting and minor editing excepted). Their inclusion in this publication does not necessarily constitute endorsement by the editors, ICDVRAT, ArtAbilitation or the University of Reading.

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Introduction

The purpose of the 7th International Conference on Disability, Virtual Reality and Associated Technologies (ICDVRAT 2008) is to provide a forum for international experts, researchers and user groups to present and review how advances in the general area of Virtual Reality can be used to assist people with Disability.

After a peer review process, the International Programme Committee selected 47 papers for presentation at the conference, collected into 9 plenary sessions: Cognitive Rehabilitation; Neurological Dysfunction; Virtual Reality Methodologies I & II; Communication & Interaction; ArtAbilitation; Motor Rehabilitation; Visual & Hearing Impairment; and Helping Through Music. The conference will host two keynote addresses and will conclude with a special panel session.

Skip Rizzo will present a review of Clinical Virtual Reality over the past decade and his view on where it is going in the next decade, while Rob Astur will present a review of how virtual reality is used to look at brain function and provide insights into psychological disorders. There is an additional session specifically for informal demonstrations, poster presentations and exhibits from a small number of companies. The conference will close with a special panel session Interpretations, featuring the *Orquestra Nacional do Porto*, which is based on the concept of inclusive appreciation of classical music performances via sensory substitution.

The conference will be held over three days between the 8th and 10th September at the Maia Forum, in Maia, Portugal, with the special sessions Helping Through Music and Interpretations on the 11th of September, 2008, in the architecturally critically acclaimed Casa da Música in the nearby city of Porto.

ICDVRAT is now in its 12th year, with biennial conferences in the series previously held in Maidenhead, UK (1996), Skövde, Sweden (1998), Alghero, Sardinia, Italy (2000), Veszprém, Hungary (2002), Oxford, UK (2004) and Esbjerg, Denmark (2006). The 6th ICDVRAT saw the inauguration of a new conference on ArtAbilitation as a parallel conference. For 2008, the ICDVRAT will incorporate ArtAbilitation sessions into the main plenary presentations.

Abstracts from this conference and full papers from the previous conferences are available online from the conference web site *www.icdvrat.reading.ac.uk*. We are also pleased to be able to provide the complete ICDVRAT archive on CD-ROM with this volume.

Acknowledgements

The Conference Chairs would like to thank the Programme Committee, for their input to the conference format and focus, and for their commitment to the review process, the authors of all the papers submitted to the conference, the Organisation Committee, Conference Sponsors, and the students who help out over the period of the conference. On behalf of ICDVRAT 2008, we welcome all delegates to the Conference and sincerely hope that delegates find the conference to be of great interest.

Pedro Lopes-dos-Santos, Tamar Weiss, Tony Brooks and Paul Sharkey

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Conference Sponsors

The main sponsors of ICDVRAT 2008 and ArtAbilitation 2008 are the University of Reading, UK; the University of Porto, Portugal; Maia Forum, Maia, Portugal; Casa da Música, Porto, Portugal; the organisers of the 2nd International Conference on Art, Brain & Languages; and the Fundação para a Ciência e a Technologia, Portugal.

The conference is grateful for further support from: the University of Haifa, Israel and Aalborg University Esbjerg/Esbjerg Technical Institute, Denmark. Additional help in publicising the conference has been gratefully received from vrpsych-l@usc.edu, amongst many others.

Artwork

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Abstracts

<u>*In alphabetical order, based on first author*</u>.

SOUND=SPACE opera, **A P Almeida**, **L M Girão**, **R Gehlhaar**, **P M Rodrigues**, **P Neto** and **M Mónica**, Fundação Casa da Música/Universidade Nova de Lisboa/Artshare Lda., Aveiro, PORTUGAL and University of Plymouth/Coventry University, UK

Over a period of three and a half months an artistic project using Rolf Gehlhaar's SOUND=SPACE, was held at Casa da Música, Porto, Portugal, in the context of the meeting «*Ao Alcance de Todos*», with a group of young people with special needs. Two final performances were the public surface of a very rewarding process that improved the quality of life of those who participated.

Functional Magnetic Resonance Imaging (fMRI) and virtual reality: adding brain imaging to your virtual reality repertoire, **R S Astur**, Hartford Hospital/Yale University, USA

Investigating the neural bases of human behavior is a remarkably complex process. In the 20th century, the traditional tools available to researchers have typically involved studying behavioral changes following a brain injury or lesion, as well as a number of physiology measures such as recording and stimulating brain areas (either inter-operatively or chronically during medical telemetry, often implemented to localize epileptic foci). Each of these has made unique contributions in providing insights into brain and behavior relations. However, such studies are invasive, and are not ideal for most purposes. This paper is designed for the VR researcher who has interest in using functional brain mapping during VR research, but who is unsure of the various issues that are involved in such a venture. Included are some of the main factors that one should consider in starting VR/fMRI experiments, and common solutions to problems that arise are provided. This primer can be used by anybody, ranging from the new graduate student with no research funds available to a full professor with generous available funds and unlimited staff.

Visual eye disease simulator, **D Banks** and **R J McCrindle**, University of Reading, UK

Visually impaired people have a very different view of the world such that a seemingly simple environment as viewed by a normal sighted person can be difficult for with those with visual impairment to access and move around. This is a problem that can be hard to fully comprehend by people with 'normal vision' even when guidelines for inclusive design are available. This paper investigates ways in which image processing techniques can be used to simulate the characteristics of a number of common visual impairments in order to provide, planners, designers and architects, with a visual representation of how people with visual impairments view their environment, thereby promoting greater understanding of the issues, the creation of more accessible buildings and public spaces and increased accessibility for visually impaired people in everyday situations.

Collaborative puzzle game – an interface for studying collaboration and social interaction for children who are typically developed or who have Autistic Spectrum Disorder, **A Battocchi**, **E Gal**, **A Ben Sasson**, **F Pianesi**, **P Venuti**, **M Zancanaro** and **P L Weiss**, University of Trento/Fondazione Bruno Kessler, ITALY and University of Haifa, ISRAEL

In this paper we present the design and some initial observations of the Collaborative Puzzle Game, an interactive play system designed with two main purposes: 1) to study social interactions and collaboration in boys with Autistic Spectrum Disorders and with typical development, and 2) to test the feasibility of the system as an instrument for the rehabilitation of social abilities of boys with ASD. Designed to run on the DiamondTouch, an interactive table supporting multi-user interaction, the CPG allows to implement "enforced collaboration", an interaction paradigm where actions on digital objects that can be performed only through the simultaneous touch of two or more users.

Exploration of computer games in rehabilitation for brain damage, **J Broeren**, **A-L Bellner**, **M Fogelberg**, **O Göransson**, **D Goude**, **B Johansson**, **P A Larsson**, **K Pettersson** and **M Rydmark**, Sahlgrenska University Hospital/Göteborg University/Primary Care and Municipality Uddevalla/Fyrbodal Research Institute/ Uddevalla Hospital, SWEDEN

Cognitive and physical deficits are consequences of stroke/traumatic brain injuries (TBI). Without rehabilitation activity problems persist i.e. limitations to handle personal care, the work situation, and recreational activities. The aim of this study is to test an application of Virtual Reality (VR) technology with 3D computer games as an occupational therapy assessment/treatment method in rehabilitation for patients with cognitive and physical deficits. We also wanted to investigate if playing computer games resulted in improved cognitive function. An easy-to-use semi-immersive workbench with haptic game selection menu was located at an activity centre. The training activities were 3D computer games. Every time an activity was run, data about the hand movements were collected and analyzed. Quantitative variables were time (s) to perform the test, average velocity (m/s) and, tremor or uncertainty in movements HPR). Executive functioning was examined by utilizing Trial Making Test. The intervention involved five patients. Results provide evidence to support the use of 3D computer games in cognitive rehabilitation. As an implementation tool within the occupational therapy area, this technology seems to be well adapted to the technological and economical development of society in Sweden.

Interpretations: inter-sensory stimulation concept targeting inclusive access offering appreciation of classical music for all ages, standing, & disability, **A L Brooks**, Aalborg University Esbjerg, DENMARK

'SoundScapes' is a body of empirical research that for almost two decades has focused upon investigating non-invasive gesture control of multisensory stimuli and potential uses. Especially targeted are disabled people of all ages, and a special focus on the profoundly impaired who have limited opportunities for creative self-articulation and playful interaction. The concept has been explored in various situations including: live stage performances; interactive room installations for museums, workshops, and festivals; and in healthcare sessions at hospitals, institutes and special schools. Multifaceted aspects continuously cross-inform in a systemic manner, and, in line with Eaglestone & Bamidis (2008), each situation where the motion-sensitive environment is applied is considered as a hybrid system. The presented preliminary work exemplifies the motion-sensitive environment and how it is used to elicit dynamic performance data from a situation that features the Orquestra Nacional do Porto. A goal is to complement the music by offering an experience of inter-sensory stimulation. Inclusive access is planned in order that all may have an opportunity to appreciate classical music. This paper reports on the background, the targeted experience, and future plans of the concept.

Towards a platform of alternative and adaptive interactive systems for idiosyncratic special needs, **A L Brooks**, Aalborg University Esbjerg, DENMARK

Eight participatory workshops were created as a hybrid situation wherein physical and virtual environments were designed to investigate responses of attendees when empowered by non-invasive sensor technology to interactively control responsive multimedia through motion. 144 disabled children and adults attended with caregivers and helpers. Targeted were fun experiences, social interactions, and recognised achievements. Evident was that the majority of disabled attendees joyfully, freely and creatively self-articulated and playfully interacted. However, traditional caregiver role in such situations is questioned following observations from the workshops. Specific design issues, targeted effect-goals, and attendee responses are reported in the paper. Conclusions reflect how such hybrid situations can offer opportunities to assess the dynamic relationships between technical set-ups and related human responses. Strategies are proposed towards future inter/multidisciplinary open research platforms to more fully examine potentials of motion-sensitive environments for this segment of society.

Remote mobility and navigation aid for the visually disabled, **M Bujacz**, **P Barański**, **M Morański**, **P Strumiłło** and **M Materka**, Technical University of Łódź, POLAND

Outdoor tests of a system for remote guidance of the blind are reported in the paper. The main idea of the system is to transmit a video stream from a camera carried by a visually impaired user to a remote assistant that navigates the blind by short spoken instructions. The communication link is established over the GSM network within the High-Speed Downlink Packet Access (HSDPA) communication protocol. Mobility trials of the system were carried out with a mobile prototype and three blind volunteers in the university campus. The aim of the study was to test the overall tele-assistance concept including: communication link efficiency and reliability, influence on mobility and safety, and the improvement of operator-user interaction. Tests, albeit performed on a small group of volunteers, clearly show an objective performance increase when traveling with the remote guide. This is evident primarily in increased travel speeds and decreased occurrences of missteps and collisions.

An infrared sound and music controller for users with specific needs, **B P Challis** and **K Challis**, University of Glamorgan, UK/Education Bradford, UK

The design and rationale behind a novel music and sound controller ("The Benemin") is described. Using an array of eight low-cost infrared distance measuring sensors, the system enables users to trigger and manipulate sounds using MIDI messages. Although the controller can facilitate complex musical interaction, providing eight note polyphony and expressive control, the central theme of the project has been one of accessibility. The controller is designed to be used in a variety of settings by users with special needs and has been designed to be both intuitive to play and easy to set up. An ongoing programme of user testing is described and discussed alongside preliminary results.

Virtual reality system for upper extremity rehabilitation of chronic stroke patients living in the community, **A Chortis**, **P J Standen** and **M Walker**, University of Nottingham, UK

For stroke patients with residual motor impairment, access to sufficient rehabilitation after discharge is often difficult to achieve due to cost, distance and availability of rehabilitative services. Virtual Reality (VR) rehabilitation is a promising method for maximizing the intensity and convenience of task specific rehabilitation training. However, many of the systems that have been developed are expensive, heavy and require frequent technical support. This feasibility study was the first phase in the evaluation of a commercially available game controller for leisure-based therapy at home. Eight people at least six months post stroke took part in a two group randomised control trial. Participants completed a range of measures of upper limb functioning before half spent three sessions a week playing computer games using the game controller while the other half spent the same amount of time in a progressive muscle relaxation program. The study is still underway so data are presented on the performance of the participants in the games group. Their results so far suggest that participants have the potential to improve their performance on the games available using this device.

Aphasic theatre or theatre boosting self-esteem, **I Côté**, **L Getty** and **R Gaulin**, Théâtre Aphasique Montréal/Université de Montréal, CANADA

Aphasia is an acquired communication disorder caused by a brain damage that can affect the ability to speak and understand, as well as to read and write. Aphasia is most commonly caused by a stroke, but it can also result from a traumatic brain injury or a tumor. Having lost normal communication skills, an aphasic victim will often hide and isolate him or herself. This can also occur as a result of a reduced level of activity following rehabilitation. To help cope with this condition and in order to help victims regain their self-esteem, the Aphasic Theatre was created in 1992. The objective was to involve interested victims in drama and theatre as a way to rehabilitating their communication skills and self-esteem. The Aphasic Theatre is today a recognized theater company which has put on plays in Quebec as well as elsewhere in Canada and Europe. There is now an accumulation of recorded evidence, from specialists, aphasic participants and their relatives, audience attending Aphasic Theatre performances as well as a study completed by ESPACE group of University of Montreal, to confirm the validity of this innovative social rehabilitation method.

Virtual reality in the rehabilitation of the upper limb after hemiplegic stroke: a randomised pilot study, **J H Crosbie**, **S Lennon**, **M C McGoldrick**, **M D J McNeill**, **J W Burke**, and **S M McDonough**, University of Ulster, N. IRELAND

The aim of this study was to assess the feasibility of an RCT to investigate VR mediated therapy in comparison to standard physiotherapy alone in the motor rehabilitation of the upper limb following stroke, and to provide data to inform a power analysis to determine numbers for a future trial. A single blinded randomised controlled trial was conducted. Participants were recruited from two hospital stroke units and members of local Northern Ireland Chest, Heart and Stroke Association clubs. The Upper Limb Motricity Index, Action Research Arm Test were completed at baseline, post-intervention and 6 weeks follow-up. 18 participants were randomised to either a VR mediated upper limb therapy group or a standard therapy group. No significant between group differences were noted. Both groups reported some small changes to their upper limb activity levels. Both interventions seemed to have been acceptable to participants. This study demonstrated the feasibility of a randomised controlled trial of virtual reality mediated therapy for the upper limb compared to standard therapy. Forty-eight participants (24 per group) would be needed to complete an adequately powered study.

Accessible virtual environments for people who are blind – creating an intelligent virtual cane using the Nintendo Wii controller, **L Evett**, **D J Brown**, **S Battersby**, **A Ridley** and **P Smith**, Nottingham Trent University, UK

People who are blind tend to adopt sequential, route-based strategies for moving around the world. Common strategies take the self as the main frame of reference, but those who perform better in navigational tasks use more spatial, map-based strategies. Training in such strategies can improve performance. Virtual Environments have great potential, both for allowing people who are blind to explore new spaces, reducing their reliance on guides, and aiding development of more efficient spatial maps and strategies. Importantly, Lahav and Mioduser have demonstrated that, when exploring virtual spaces, people who are blind use more and different strategies than when exploring real physical spaces, and develop relatively accurate spatial representations of them. The present paper describes the design, development and evaluation of a system in which a virtual environment may be explored by people who are blind using Nintendo Wii devices, with auditory and haptic feedback. Using this technology has many advantages, not least of which are that it is mainstream, readily available and cheap. The utility of the system for exploration and navigation is demonstrated. Results strongly suggest that it allows and supports the development of spatial maps and strategies. Intelligent support is discussed.

Virtual reality rehabilitation – what do users with disabilities want?, **S M Flynn**, **B S Lange**, **S C Yeh** and **A A Rizzo**, University of Southern California, USA

This paper will discuss preliminary findings of user preferences regarding video game and VR game-based motor rehabilitation systems within a physical therapy clinic for patients with SCI, TBI and amputation. The video game and VR systems chosen for this research were the Sony PlayStation® 2 EyeToy™, Nintendo® Wii™, and Novint® Falcon™ and an optical tracking system developed at the Institute for Creative Technologies at the University of Southern California. The overall goals of the current project were to 1) identify and define user preferences regarding the VR games and interactive systems; 2) develop new games, or manipulate the current USC-ICT games to address these user-defined characteristics that were most enjoyable and motivating to use; and 3) develop and pilot test a training protocol aimed to improve function in each of the three groups (TBI, SCI and amputation). The first goal of this research will be discussed in this paper.

Robotic assisted rehabilitation in virtual reality with the L-EXOS, **A Frisoli**, **M Bergamasco**, **L Borelli**, **A Montagner**, **C Procopio**, **M C Carboncini** and **B Rossi**, Scuola Superiore Sant'Anna/University of Pisa, ITALY

This paper presents the results of a clinical trial employing the PERCRO L-Exos (Light-Exoskeleton) system, which is a 5-DoF force-feedback exoskeleton for the right arm, for robotic-assisted rehabilitation. The device has demonstrated itself suitable for robotic arm rehabilitation therapy when integrated with a Virtual Reality (VR) system. Three different schemes of therapy in VR have been tested in the clinical evaluation trial, which was conducted at the Santa Chiara Hospital in Pisa with nine chronic stroke patients. The results of this clinical trial, both in terms of patients performance improvements in the proposed exercises and in terms of improvements in the standard clinical scales which have been used to monitor patients progresses will be reported and discussed throughout the paper. The evaluation both pre and post-therapy was carried out with both clinical and quantitative measurements with EMG and motion data; the latter ones measured in terms of different kinetic parameters estimated through the online data logged during the repeated sessions of exercise. It is to be noted that statistically significant improvements have been demonstrated in terms of Fugl-Meyer scores, Ashworth scale, increments of active and passive ranges of motion on shoulder, elbow and wrist joints of the impaired limb, active and passive, and quantitative indexes, such as task time and error, synergies and smoothness of movement.

CaDaReMi: an educational interactive music game, **R Gehlhaar**, **P M Rodrigues** and **L M Girão**, Coventry University/University of Plymouth, UK and Artshare Lda., Aveiro/Fundação Casa da Música, PORTUGAL

This new multi-user interactive sound installation (≤ 8 persons simultaneously) implements proprietary glob-recognition and tracking software in order to allow visitors to a large empty space (~5m × 7m) to move an avatar - projected on a screen at the end of the space – simply by moving about the space, with the objective of taking it to specific, recognizable locations. Success in this endeavour causes sounds to be triggered.

Passages – a 3D artistic interface for child rehabilitation and special needs, **F Ghedini**, **H Faste**, **M Carrozzino** and **M Bergamasco**, Scuola Superiore Sant'Anna/IMT Institute for Advanced Studies, ITALY

Passages is an immersive, multimodal, user-controlled artistic interface. It consists of a three-dimensional interactive Virtual Environment that can be created, explored and interacted with in real-time. The installation has been exhibited in Grenoble, France, during the ENACTION_in_Arts conference (November 19-24, 2007) and in Pisa, Italy, during the Beyond Movement workshop (December 17-21, 2007). This paper outlines the design of the artistic installation *Passages,* and its potential in the field of rehabilitation.

Making music with images: interactive audiovisual performance systems for the deaf, **M Grierson**, Goldsmiths College, UK

This paper describes the technical and aesthetic approach utilised for the development of an interactive audiovisual performance system designed specifically for use by children with multiple learning difficulties, including deafness and autism. Sound is transformed in real-time through the implementation of a Fast Fourier Transform (FFT) and translated into a moving image. This image is adapted so that relevant information can be understood and manipulated visually in real-time. Finally, the image is turned back into sound with only minimal delay. The translation process is based on research in computer music, neuroscience, perception and abstract film studies, supported by the Arts and Humanities Research Council. The system has been developed through collaboration with the Sonic Arts Network, Whitefields Special Needs School, and the South Bank Centre, specifically for a project led by Duncan Chapman with the London Philharmonic Orchestra. The system has now been made available for free by the Sonic Arts Network.

The effect of game speed and surface perturbations on postural control in a virtual environment, **P J R Hawkins**, **M B Hawken** and **G J Barton**, Liverpool John Moores University, UK

The aim of this study was to describe the relationship between performance and difficulty set by altering game velocity and surface perturbations in a virtual game environment. Performance deteriorates as game difficulty increases when changing game velocity and surface perturbations. Adjustment of both game velocity and the introduction of surface perturbations independently appear to be simple and effective methods of customising task difficulty as a function of patients' motor ability during rehabilitation.

Tele-evaluation and intervention among adolescents with handwriting difficulties – Computerized Penmanship Evaluation Tool (ComPET) implementation, **L Hen**, **N Josman** and **S Rosenblum**, University of Haifa, ISRAEL

Writing is a complex and essential human activity. During adolescence, there is an increase in the complexity and quantity of writing required for communication, self-expression, and for demonstrating academic ability. Deficits in handwriting performance limit the writing abilities, and hence the participation of adolescents in many areas of life. Computer-based tele-rehabilitation has the potential to address handwriting assessment and treatment. The goal of the present study is to examine the potential of the ComPET as a tool to assess and treat adolescents with handwriting difficulties. A case report is presented.

Customization of gaming technology and prototyping of rehabilitation applications, **B Herbelin**, **J Ciger** and **A L Brooks**, Aalborg University Esbjerg, DENMARK

The field of rehabilitation has recently seen various experimentations with games using interfaces that require physical activity. In order to establish the basis for developments and experimentations with those interactive systems, we propose a rapid prototyping approach using various commercial devices and open source software. To demonstrate this idea, we first show how a simple free game can be adapted to specific needs— for training or use by disabled people— by using different sensors and control modes. Similarly, we show that an open on-line virtual world such as Second Life, although not perfect, offers sufficient conditions for quickly building custom content and testing with usual interactive devices. When presented to these prototyping possibilities, people from the target group (health care professionals, patients, handicapped, families) are able to relate to their needs and to elaborate on the use of such systems. In other words, the availability of a simple prototyping platform with free games and new interfaces already opens the discussion on the design of original rehabilitation applications.

Performance within the virtual action planning supermarket (VAP-S): an executive function profile of three different populations suffering from deficits in the central nervous system, **N Josman**, **E Klinger** and **R Kizony**, University of Haifa, ISRAEL and Arts et Métiers ParisTech, Angers-Laval, FRANCE

Executive functions are those higher-order functions required for performing complex or non-routine tasks. People exhibiting Central Nervous System (CNS) deficits often manifest impaired executive functions, compromising return to full everyday activity and occupation. Such individuals have difficulty performing mundane daily living activities, and especially complex activities – termed Instrumental Activities of Daily Living (IADL). The use of ecologically valid, functional virtual environments constitutes a novel solution to evaluation. The Virtual Action Planning Supermarket (VAP-S) allowed us to compare performance among 3 groups of clients: post-stroke, Minimal Cognitive Impaired, and schizophrenics, and to analyze predictive group membership of the clients (N=83). Results supported study objectives, revealing distinctive performance profiles per group.

Interactive training of speech articulation for hearing impaired using a talking robot, **M Kitani**, **Y Hayashi** and **H Sawada**, Kagawa University, JAPAN

This paper introduces a speech training system for auditory impaired people employing a talking robot. The talking robot consists of mechanically-designed vocal organs such as a vocal tract, a nasal cavity, artificial vocal cords, an air pump and a sound analyzer with a microphone system, and the mechanical parts are controlled by 10 servomotors in total for generating human-like voices. The robot autonomously learns the relation between motor control parameters and the generated vocal sounds by an auditory feedback control, in which a Self-organizing Neural Network (SONN) is employed for the adaptive learning. By employing the robot and its properties, we have constructed an interactive training system. The training is divided into two approaches; one is to use the talking robot for showing the shape and the motion of the vocal organs, and the other is to use a topological map for presenting the difference of phonetic features of a trainee's voices. While referring to the vocal tract motions and the phonetic characteristics, a trainee is able to interactively practice vocalization for acquiring clear speech with an appropriate speech articulation. To assess the validity of the training system, a practical experiment was conducted in a school for the deaf children. Nineteen subjects took part in the interactive training with the robotic system, and significant results were obtained. The talking robot is expected to intensively teach an auditory impaired the vocalization skill by directing the difference between clear speech and the speech with low clarity.

You are who you know: user authentication by face recognition, **M Klíma**, **A J Sporka** and **J Franc**, Czech Technical University in Prague/Sun Microsystems, Inc, CZECH REPUBLIC and University of Trento, ITALY

In this paper, a novel method of authentication based on user-performed identification of known and unknown faces is described. The target group of the method is the elderly users for which the use of traditional techniques, such as passwords, personal identification numbers (PIN), or biometrics is not without problems. The performance of this method and authentication by PIN has been compared in a two-pass usability study. Our method performed significantly better than PIN. The method is suitable for low-security applications in hospitals and senior houses.

Changes in electroencephalographic spike activity of patients with focal epilepsy through modulation of the sensory motor rhythm in a brain-computer interface, **R J Lopes**, **P S Gamito**, **J A Oliveira**, **L H Miranda**, **J C Sousa** and **A J Leal**, Universidade Lusófona de Humanidades e Tecnologias/Universidade Nova de Lisboa/Hospital Júlio de Matos/Hospital Dona Estefânia, PORTUGAL

In epilepsy persistence of seizures, despite appropriate pharmacological therapy, motivates referral to surgery of epilepsy, currently the most effective treatment. Because surgery is not indicated for all patients, search for alternative therapies is ongoing. Preliminary data suggests the potential benefit of sensory-motor rhythm modulation on the epileptic activity. However, no controlled studies have been performed. Our study evaluates the benefits of sensory-motor rhythm training to reduce spike activity in Rolandic epilepsy patients with frequent spike activity. Using a Brain-Computer Interface, we obtained a statistically significant modulation of the Mu rhythm and variation of interictal spike activity.

Virtual reality and associated technologies in disability research and intervention, **P Lopes-dos-Santos**, **M Maia**, **A Tavares**, **M Santos** and **M Sanches-Ferreira**, University of Porto/Porto Polytechnic School of Education, PORTUGAL

This paper concerns the application of virtual reality and associated technologies (VRAT) in the disability research and intervention field. By reviewing 144 studies presented at the International Conference Series on Disability, Virtual Reality and Associated Technologies (1996-2006), our analytic work examine the underlying conceptual frameworks of disability and methodological rationales used in selected papers. In the last 15 years, there was a paradigmatic shift from the medical to the biopsychosocial model of disability. Yet, our analyses indicate that such shift is not clearly reflected in the way VRAT have been addressing disability issues. The present manuscript offers recommendations regarding definition of goals, methodological procedures, and assessment rationales in order to stimulate discussions on how the use of VRAT can be improved in the field of disability research and practice.

Using immersion in a musical virtual space environment to enhance quality of body movement in young adults with hemiparesis, **P Lopes-dos-Santos**, **A Nanim**, **H Fernandes** and **J Levi**, University of Porto/UADIP/Balleteatro, Portugal

This paper focuses on the application of musical virtual space environments in the rehabilitation of individuals with motor disabilities. It is contended that the use of such environments has the potential of enhancing performance through engagement of the person in meaningful and functional activities. Our study describes and evaluates the use of a musical virtual space to increase the quality of movement and improve gross motor functioning in four young adults with hemiparesis. Results showed that immersion episodes in the musical virtual environment provided highly engaging experiences that fostered body movement and social interaction. After twenty immersive sessions, participants revealed gains in the aesthetic quality of gestures performed in dancing responses to music. There were also significant improvements regarding gross motor functions, namely in parameters such as stability, coordination, flow, effort, and mobility.

Virtual reality and neuropsychology: a cognitive rehabilitation approach for people with psychiatric disabilities, **A Marques**, **C Queirós** and **N Rocha**, Oporto Polytechnic Institute/University of Porto, PORTUGAL

This pilot-study evaluated the feasibility of a 9 month Cognitive Rehabilitation Program – using Virtual Reality and the Integrated Psychological Therapy (IPT) – to improve cognitive functioning in people with schizophrenia. In order to assess the program it was applied (pre and post) the WCST, WAIS-III sub-tests, Stroop Test, and The Subjective Scale to Investigate Cognition in Schizophrenia. Results identified significant differences ($p<0.05$) between pre and post tests in the subjective and objective assessed cognitive dimensions. The results point out that virtual reality technology and IPT may be a significant resource and intervention methodology in the cognitive remediation of people with psychiatric disabilities.

Mix-it-yourself with a brain-computer music interface, **E R Miranda** and **V Soucaret**, University of Plymouth, UK

This paper is a follow up from the work presented at the ICDVRAT 2006 conference in Esbjerg, where the first author introduced a Brain-Computer Music Interface (BCMI) to control a generative music system. Here we introduce a new musical application for the BCMI (an EEG-controlled music mixer) and report on efforts to make our BCMI system cheaper to implement, more portable and easier for users to operate. We also comment on a new method that we are developing to generate melodies from the topological behaviour of the EEG.

Low-cost optical tracking for immersive collaboration in the CAVE using the Wii Remote, **A Murgia**, **R Wolff**, **P M Sharkey** and **B Clark**, University of Reading/ University of Salford, UK

We present a novel way of interacting with an immersive virtual environment which involves inexpensive motion-capture using the Wii Remote. A software framework is also presented to visualize and share this information across two remote CAVE-like environments. The resulting applications can be used to assist rehabilitation by sending motion information across remote sites. The application's software and hardware components are scalable enough to be used on desktop computer when home-based rehabilitation is preferred.

Virtual reality, haptics and post-stroke rehabilitation in practical therapy, **L Pareto**, **J Broeren**, **D Goude** and **M Rydmark**, University West, Trollhättan/Curictus AB, Kista/Göteborg University/Sahlgrenska University Hospital, SWEDEN

We address the question of *usefulness* of virtual reality based rehabilitation equipment in practical therapy, by letting experienced therapists explore one such equipment during six months in their regular practice under natural circumstances. By protocols, questionnaires and focus group interviews we collect data regarding which activities they considered useful, why these are useful and what might improve usefulness of such activities, based on the therapists' professional judgement and experiences. This resulted in a set of purposeful activities, identified values for therapeutic work, and design guidelines. The conclusion is that such equipment has benefits beyond real life training, that variation in content and difficulty levels is a key quality for wide suitability and that the combination of challenging cognitive activities which encourage motor training was considered particularly useful.

Virtual human patients for training of clinical interview and communication skills, **T D Parsons**, **P Kenny** and **A A Rizzo**, University of Southern California, USA

Although schools commonly make use of standardized patients to teach interview skills, the diversity of the scenarios standardized patients can characterize is limited by availability of human actors. Virtual Human Agent technology has evolved to a point where researchers may begin developing mental health applications that make use of virtual reality patients. The work presented here is a preliminary attempt at what we believe to be a large application area. Herein we describe an ongoing study of our virtual patients. We present an approach that allows novice mental health clinicians to conduct an interview with virtual character that emulates 1) an adolescent male with conduct disorder; and 2) an adolescent female who has recently been physically traumatized.

Neuropsychological assessment using the virtual reality cognitive performance assessment test, **T D Parsons** and **A A Rizzo**, University of Southern California, USA

The traditional approach to assessing neurocognitive performance makes use of paper and pencil neuropsychological assessments. This received approach has been criticized as limited in the area of ecological validity. The newly developed Virtual Reality Cognitive Performance Assessment Test (VRCPAT) focuses upon enhanced ecological validity using virtual environment scenarios to assess neurocognitive processing. The VRCPAT battery and a neuropsychological assessment were conducted with a sample of healthy adults. Findings suggest 1) good construct validity for the Memory Module; and 2) that increase in stimulus complexity and stimulus intensity can manipulate attention performance within the Attention Module.

HARMiS – hand and arm rehabilitation system, **J Podobnik**, **M Munih** and **J Cinkelj**, University of Ljubljana, SLOVENIA

This paper presents the HARMiS device (Hand and arm rehabilitation system), which is primarily intended for use in robot-aided neurorehabilitation and for training of reaching, grasping and transporting virtual objects in haptic environments. System combines haptic interface and module for grasping, which is mounted on the top of the haptic interface. This allows combined training of the upper extremity movements and grasping. High level of reality is achieved with use of the graphic and haptic visual environments, which is beneficial for the motivation of the patients.

Examination of users' routes in virtual environments, **C Rigó** and **C Sik Lányi**, University of Pannonia, HUNGARY

We developed three virtual environments (VEs): a VR gallery, a VR store and a VR labyrinth for the investigation of the users' routes in these VEs. In this article we examine the matching of these tours with two developed utilities. From the results we want to draw the inference to the practical development of the virtual environments for defined groups of users. We examined left-handed, right-handed persons and people who play often with VR games as well as people who play with VR games rarely or never. The VE and the developed testing frame software are adaptable for every disabled group's route examination.

Virtual reality in psychology and rehabilitation: the last ten years and the next!, **A A Rizzo**, Institute for Creative Technologies, University of Southern California, USA

Virtual reality (VR) has undergone a transition in the past 10 years that has taken it from the realm of expensive toy and into that of functional technology. Revolutionary advances in the underlying VR enabling technologies (i.e., computation speed and power, graphics and image rendering technology, display systems, interface devices, immersive audio, haptics tools, tracking, intelligent agents, and authoring software) have supported development resulting in more powerful, low-cost PC-driven VR systems. Such advances in technological "prowess" and accessibility have provided the hardware platforms needed for the conduct of human research and treatment within more usable, useful and lower cost VR systems. At the same time, there has been a growing awareness of the potential value of VR by scientists and clinicians, in addition to the general public. While much of this recognition may be due to the high visibility of digital games and massive shared internet-based virtual worlds (World of Warcraft, Halo and 2nd Life), clinical research applications routinely come into the public consciousness via the popular media. Whether this can be considered as "hype" or "help" to a field that has a storied history of alternating periods of public enchantment and disregard, still remains to be seen. Regardless, growing public awareness coupled with solid scientific results delivered from VR clinical and research applications have brought the field past the point where sceptics can be taken seriously when they characterize VR as a "fad technology". It is not 1998 anymore! This paper charts the past 10 years of progress and anticipates development in the field over the next decade.

Virtual reality Post Traumatic Stress Disorder (PTSD) exposure therapy results with active duty Iraq war combatants, **A A Rizzo**, **G Reger**, **K Perlman**, **B Rothbaum**, **J Difede**, **R McLay**, **K Graap**, **G Gahm**, **S Johnson**, **R Deal**, **J Pair**, **T D Parsons**, **M Roy**, **R Shilling** and **P M Sharkey**, University of Southern California/Naval Medical Center – San Diego/Emory University School of Medicine/Weill Medical College of Cornell University/Madigan Army Medical Center – Ft. Lewis/Virtually Better, Inc/Walter Reed Army Medical Center/Office of Naval Research, USA and University of Reading, UK

Post Traumatic Stress Disorder (PTSD) is reported to be caused by traumatic events that are outside the range of usual human experience including (but not limited to) military combat, violent personal assault, being kidnapped or taken hostage and terrorist attacks. Initial data suggests that at least 1 out of 6 Iraq War veterans are exhibiting symptoms of depression, anxiety and PTSD. Virtual Reality (VR) delivered exposure therapy for PTSD has been used with reports of positive outcomes. The aim of the current paper is to present the rationale and brief description of a *Virtual Iraq* PTSD VR therapy application and present initial findings from its use with PTSD patients. Thus far, *Virtual Iraq* consists of a series of customizable virtual scenarios designed to represent relevant Middle Eastern VR contexts for exposure therapy, including a city and desert road convoy environment. User-centered design feedback needed to iteratively evolve the system was gathered from returning Iraq War veterans in the USA and from a system deployed in Iraq and tested by an Army Combat Stress Control Team. Results from an open clinical trial at San Diego Naval Medical Center of the first 18 treatment completers indicate that 14 no longer meet PTSD diagnostic criteria at post-treatment, with only one not maintaining treatment gains at 3 month follow-up. Clinical tests are also currently underway at Ft. Lewis, Emory University, Weill Cornell Medical College, Walter Reed Army Medical Center and 10 other sites. Other sites are preparing to use the application for a variety of PTSD and VR research purposes.

Mobile audio assistance in bus transportation for the blind, **J H Sánchez** and **C A Oyarzún**, University of Chile, CHILE

People with visual disabilities have serious difficulties when mobilizing through the city on the public transportation system. We introduce *AudioTransantiago*, a handheld application that allows users to plan trips and provide contextual information during the journey through the use of synthesized voices. The usability and cognitive evaluation of *AudioTransantiago* was performed using a prototype evaluation in order to identify and solve usability issues, ending up with an intuitive and simple interface. Finally, a cognitive impact evaluation administered during bus trips taken with the assistance of *AudioTransantiago* demonstrated that the software provides more autonomy and effectiveness for users' trips, improving their orientation and mobility.

Effects of different virtual reality environments on experimental pain threshold in individuals with pain following stroke, **M J Simmonds** and **S Shahrbanian**, McGill University, CANADA

The objectives of this study were to determine whether different virtual reality environments (VR) had a differential effect on pain threshold (PT) in stroke patients with pain, and whether the patient's level of interest in the VR influenced PT. Ten stroke individuals with pain participated. PT to hot and cold stimuli was determined using Quantitative sensory testing within four different VEs; Hot, Cold, Neutral and no VR. After the VR exposure, subjects rated each VR condition based on their engagement. The results suggest that VR is more effective than no VR and all VR conditions were more engaging than no VR.

Providing disabled persons in developing countries access to computer games through a novel gaming input device, **A C Smith** and **C Krause**, African Advanced Institute for Information & Communications Technology, SOUTH AFRICA

A novel input device for use with a personal computer by persons with physical disabilities who would otherwise not be able to enjoy computer gaming is presented. This device is simple to manufacture and low cost. We describe the constituent parts of this device. A collaboration gaming application especially designed for this input device is given in brief.

Effect of playing computer games on decision making in people with intellectual disabilities, **P J Standen**, **F Rees** and **D J Brown**, University of Nottingham/Nottingham Trent University, UK

People with intellectual disabilities have difficulty making decisions and this may hinder their independence and inclusion in society. Interactive computer software may give them the opportunity to practice the underlying components of this skill. A previous study indicated that playing a computer game improved choice reaction time. This study aimed to discover if repeated sessions playing a computer game involving aspects of decision making, such as collecting relevant information and controlling impulsivity, would improve performance in two non-computer based tests of decision making. 12 adults with intellectual disabilities were randomly assigned to either an intervention group or control group. They were all exposed to 10 twice weekly sessions, playing either the intervention game or the control game, which involved simple reaction time only. All participants completed two non-computer based tests of decision making at baseline and post-intervention. After repeated sessions, the intervention group showed a significant improvement in game score, with researcher assistance significantly decreasing. At follow up, the intervention group showed a significant decrease from baseline in the number of guesses made before guessing correctly on both of the decision making tests. The decrease observed in the control group failed to reach significance.

Finger spelling recognition using distinctive features of hand shape, **Y Tabata** and **T Kuroda**, Kyoto College of Medical Science/Osaka University, JAPAN

The authors have been developing a glove based input device, called "Stringlove", recognizing finger shapes by adapting for several shapes pointing an angle of each finger joint. A research group reports on the sign language linguistics features to distinguish finger shapes, and advance to make it practicable to engineering. This paper mentions that the method of recognition of finger shapes was examined by using the developing equipment. According to a preliminary experiment, it has been suggested that the present method has a good possibility to improve a rate of recognition of finger shapes.

Cognitive effects of videogames on old people, **A Torres**, University of Porto/ University of Aveiro, PORTUGAL

In these days the percentage of older people in the population is growing worldwide. It is therefore urgent to decrease the morbidity resulting from biopsychosocial losses associated with old age. The preservation and recovery of cognitive functions and of physical, psychological and social autonomy are provided through new mental and physical activities. As have other activities, the use of video games has shown benefits for this ageing population, in particular at the cognitive level. Although there are only few studies which studied this videogames' application. In this study we studied the cognitive effects of videogames on the elderly people. And we also studied these effects on self-concept and on the quality of life. The instruments used are the Cognitive Sub-scale of Alzheimer's Disease Assessment Scale, the Clinical Inventory of Self-Concept and the WHOQOL-Bref. The study involved the participation of 43 elderly people distributed between 3 experimental conditions (n = 15 used videogames, n = 17 relaxation and n =11 had no intervention). There were two moments of assessment, before the intervention (Pre-test) and after eight weeks of it (Post-Test). Old people shows to be able to use videogames as well as to like to use it. Although they faced some difficulties using key board and mousse. They show to prefer games without time challenge and without fast and exact movements. They also show to prefer videogames with a real story behind the play activity. It was found that the videogames participants showed a decline in cognitive deterioration from the pre to post intervention tests (t (14) = 3,505, p =. 003, r = .68), unlike the control groups. The self-concept deteriorated up significantly under relaxation condition (t (16) = 2.29, p = .036, r = .50) and on passive control group (t(10) = 3.44, p = .006, r = .74). The quality of life did not show any differences from the start to the end of the study. Nor were any correlations found between the time of use of videogames and larger effects. The mediator effect of self-concept on differences obtained in the ADAS-Cog (rS = .57, p = .014) and in the ICAC (rS = -.47, p = .039) was confirmed. In sum, the results show that the use of videogames leads to the improvement of cognitive functioning and to the maintenance of the self-concept and the quality of life of elderly people. They also suggest that the higher the self-concept, the better are the cognitive effects achieved.

Auditory-visual virtual environments to treat dog phobia, **I Viaud-Delmon**, **F Znaïdi**, **N Bonneel**, **D Doukhan**, **C Suied**, **O Warusfel**, K **V N'Guyen** and **G Drettakis**, IRCAM/La Salpetriere Hospital/ REVES INRIA, FRANCE

In this paper we present the design, development, and usability testing of an auditory-visual based interactive environment for investigating virtual reality exposure-based treatment for cynophobia. The application is developed upon a framework that integrates different algorithms of the CROSSMOD project (www.crossmod.org). We discuss the on-going work and preliminary observations, so as to further the development of auditory-visual environment for virtual reality. Traditionally, virtual reality concentrates primarily on the presentation of high fidelity visual experience. We aim at demonstrating that combining adequately the visual and the auditory experience provides a powerful tool to enhance sensory processing and modulate attention.

Gazing into a Second Life: gaze-driven adventures, control barriers, and the need for disability privacy in an online virtual world, **S Vickers**, **R Bates** and **H O Istance**, De Montfort University, UK

Online virtual worlds such as Second Life and World of Warcraft offer users the chance to participate in potentially limitless virtual worlds, all via a standard desktop pc, mouse and keyboard. This paper addresses some of the interaction barriers and privacy concerns that people with disabilities may encounter when using these worlds, and introduces an avatar Turing test that should be passed for worlds to be accessible for all users. The paper then focuses on the needs of high-level motor disabled users who may use gaze control as an input modality for computer interaction. A taxonomy and survey of interaction are introduced, and an experiment in gaze based interaction is conducted within these virtual worlds. The results of the survey highlight the barriers where people with disabilities cannot interact as efficiently as able-bodied users. Finally, the paper discusses methods for enabling gaze based interaction for high-level motor disabled users and calls for game designers to consider disabled users when designing game interfaces.

Keeping an eye on the game: eye-gaze interaction with Massively Multiplayer Online Games and virtual communities for motor impaired users, **S Vickers**, **H O Istance**, **A Hyrskykari**, **N Ali** and **R Bates**, De Montfort University, UK and University of Tampere, FINLAND

Online virtual communities are becoming increasingly popular both within the able-bodied and disabled user communities. These games assume the use of keyboard and mouse as standard input devices, which in some cases is not appropriate for users with a disability. This paper explores gaze-based interaction methods and highlights the problems associated with gaze control of online virtual worlds. The paper then presents a novel 'Snap Clutch' software tool that addresses these problems and enables gaze control. The tool is tested with an experiment showing that effective gaze control is possible although task times are longer. Errors caused by gaze control are identified and potential methods for reducing these are discussed. Finally, the paper demonstrates that gaze driven locomotion can potentially achieve parity with mouse and keyboard driven locomotion, and shows that gaze is a viable modality for game based locomotion both for able-bodied and disabled users alike.

Virtual reality methodology for eliciting knowledge about public transport accessibility for people with acquired brain injury, **M Wallergård**, **J Eriksson** and **G Johansson**, Lund University, SWEDEN

The aim of this study was to investigate if and how a virtual reality-based methodology can be used to elicit knowledge about public transport accessibility for people with acquired brain injury (ABI). Four subjects with ABI and four occupational therapists made a bus trip in an immersive virtual environment. Their knowledge about public transport accessibility was elicited using the think aloud technique. All subjects managed to handle the VR methodology sufficiently well. The two subject groups tended to focus on different aspects of accessibility in public transport systems. The results suggest that a VR-based methodology can be used to elicit a wide spectrum of knowledge about public transport accessibility for people with ABI.

Unintentional intrusive participation in multimedia interactive environments, **C Williams**, Pontnewydd Primary School, WALES

This paper presents data from two independent case studies, a 15 year old female with Cerebral Palsy and related profound and multiple learning difficulties and a 7 year old male with extreme behaviour associated with Autistic Spectrum Disorder. An audiovisual immersive interactive environment was developed to encourage creative interaction and expression from the participants. There were support workers present in both case studies and it is the interventions of these support staff which are the main focus of this paper. Results indicated that profuse but unintentional interventions from the staff may have distorted interaction with, dissuaded or diverted participants from meaningful engagements with the reactive feedback provided by the system.

Just smile, you are in Maia

Pedro Lopes-dos-Santos and **Gustavo Portocarrero**

University of Porto *&* University of Lisboa, PORTUGAL

A warm welcome to Maia, one of the Portugal's youngest cities!

Maia's meeting with history took place for the first in the 10th century AD. It was then that it was formed as the *Terra da Maia* (Land of Maia). This was the name given to a territory of considerable dimension between the city of Porto and the river Ave. It was a territory formed during the context of the Christian 'Reconquista' (re-conquering) against the Muslims. After the latter's Arabian invasion of Iberian Peninsula in 711 AD, only the region around the Asturias remained fully Christian, with the big area surrounding the Douro river – where Maia presently stands – becoming a sort of no-man's-land between the antagonist forces. In the 9th and 10th centuries that situation changed and the Douro region fell under full Christian control. A number of new administrative territories called *terras* were formed and Maia was one of them.

The *Terra da Maia* was part of a larger administrative entity: the county of Portucale, which encompassed an area roughly equivalent to today's Northern Portugal. The name Portucale was the name of the city of Porto during the Roman days and the High Middle Ages. When Christians reoccupied this city in the year 868, it was from there that they started the process of reorganization and administration of the northern territories. Later, this land would become a new county of the Christian kingdom of Leon. Given the importance of Portucale, the new county was called after the city name, that is, the *Land of Portucale*.

Material testimonies of these first days of the *Terra da Maia* can be seen in the churches of Águas Santas and Salvador da Maia. These churches were part of monasteries that were established in this territory after the Christian Reconquista, though the original buildings no longer remain. At that time, the Christian warriors were always followed by religious orders, which would reorganise the social and economic life of the newly retaken territories, having therefore a fundamental role in the consolidation of the Christian order there.

But it was not only monasteries that were established here; noble families also established themselves in the region, in particular the family of the Mendes da Maia. Two members of this family were actively engaged in important events in the early 12th century that would lead to the separation of the then county of Portucale from the kingdom of Leon and its transformation in a new kingdom. They were Gonçalo Mendes da Maia, called the "Champion" (*right*), and his brother Paio Mendes da Maia, who was archbishop of the city of Braga. The former was the most notable Portuguese warrior from that period, having devoted all his life to war and who died, according to the legend, at an old age fighting against an invading army. His memory is still kept in hundreds of wondrous tales transmitted from generation to generation. Today, a statue representing the "Champion" can be seen in front of the Maia City Hall.

In 1384, this territory, which had a clear rural character, fell under the administration of the neighbouring city of Porto, starting a process of building a close relationship between Maia and Porto.

Porto was, by then, the second most important city of Portugal, after Lisbon, both in population and economic importance. The city had a strong commercial character, and its geographical location certainly favoured such activity: it was at the mouth of the (navigable) river Douro and it faced the Atlantic Ocean. It had, in that way, trade links with the Douro hinterland and with ports in the Atlantic Ocean, in particular, those from Britain. One of the products produced in the Douro hinterland and exported from Porto was a wine that would later become famous: Port wine. So, the wine ended up being known not for the place where it was produced but, instead, from the place where it was exported. Nowadays, the warehouses where this wine is kept after being brought from the hinterland are still visible in the southern bank of the Douro, in Vila Nova de Gaia, in front of which one can also find several of the traditional boats – the *rebelos* – that used to transport the wine from up river.

Porto

Unlike Maia, this was a city ruled by a strong bourgeoisie. Actually, so strong was this bourgeoisie, that for several centuries nobles could not stay more than three days, nor were they allowed to own property inside the city. This strong bourgeois character is also visible in the city's architecture. Hardly a large noble palace can be found here; instead, what is common are the tall and narrow houses where the bourgeoisie lived. Most of these houses, particularly from the 18th and 19th centuries, still survive in the city's historical centre and one can have a great sight of them from the southern bank going down the hill towards the river. So impressive is the historical centre that it is today one of UNESCO's World Heritage sites. Such designation is the result of an ongoing process of re-inventing Porto as a city of culture and science, exemplified by its *ex-libris* the notable *Casa da Música* (House of Music) and its major leading force the University of Porto.

Casa da Música

With such intense human and commercial activity going on in Porto, it is understandable why Maia ended up being part of Porto's hinterland. Maia was a fertile land with a rich agriculture and supplied the city with many staple products such as food or hemp used to make ropes for the many boats that arrived to and departed from Porto's harbour.

This relationship of direct dependence of Maia towards Porto would end only in the 1830's. During 1832–1834, the country suffered a fierce civil war between the Liberals and the Absolutists, with the *Terra da Maia* being one of the war's major battlefields. In 1832, a Liberal expeditionary force landed on the coast of *Terra da Maia* and occupied Porto. A year long siege of city by the Absolutist forces would follow. Moved by their deep democratic traditions, Porto inhabitants offered an epic resistance and the Absolutist troops had to withdraw. Another year would be needed for the war to finish. The Liberals won and one of their first measures was to remake the municipal map of Portugal. As a consequence, the old *Terra da Maia* would finish, loosing part of its territory and being reduced to its present dimensions. On the other hand, its direct administration from Porto also came to an end.

More recently, Maia has lost much of its rural character and has became the most important industrial area of the region. During these past three decades, Maia had an important population growth and emerged as a modern urban space with a proliferation of sport, cultural, and other leisure facilities. Local policies have been putting a special emphasis on health and quality of life promotion as a way to vindicate the old "maiato" folk saying: *Just smile, you're in Maia*.

ICDVRAT 2008

Keynote I

Skip Rizzo *on* Clinical Virtual Reality

Chair: Pedro Lopes-dos-Santos

Virtual reality in psychology and rehabilitation: the last ten years and the next!

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1. INTRODUCTION

Virtual reality (VR) has undergone a transition in the past 10 years that has taken it from the realm of expensive toy and into that of functional technology. Revolutionary advances in the underlying VR enabling technologies (i.e., computation speed and power, graphics and image rendering technology, display systems, interface devices, immersive audio, haptics tools, tracking, intelligent agents, and authoring software) have supported development resulting in more powerful, low-cost PC-driven VR systems. Such advances in technological "prowess" and accessibility have provided the hardware platforms needed for the conduct of human research and treatment within more usable, useful and lower cost VR systems.

At the same time, there has been a growing awareness of the potential value of VR by scientists and clinicians, in addition to the general public. While much of this recognition may be due to the high visibility of digital games and massive shared internet-based virtual worlds (World of Warcraft, Halo and 2nd Life), clinical research applications routinely come into the public consciousness via the popular media. Whether this can be considered as "hype" or "help" to a field that has a storied history of alternating periods of public enchantment and disregard, still remains to be seen. Regardless, growing public awareness coupled with solid scientific results delivered from VR clinical and research applications have brought the field past the point where skeptics can be taken seriously when they characterize VR as a "fad technology". It is not 1998 anymore!

When discussion of the potential for VR applications in the human clinical and research domains first emerged in the early-1990s, the technology needed to deliver on the anticipated "visions" was not in place. Consequently, during these early years, VR suffered from a somewhat imbalanced "expectation-to-delivery" ratio, as most users trying systems during that time will attest. The "real" thing never quite measured up to expectations generated by some of the initial media hype, as delivered for example in the films "The Lawnmower Man" and "Disclosure"! Yet the idea of producing simulated virtual environments that allowed for the systematic delivery of ecologically relevant stimulus events and challenges was compelling and made intuitive sense. As well, a long and rich history of encouraging findings from the aviation simulation literature lent support to the concept that testing, training and treatment in highly proceduralized VR simulation environments would be a useful direction for psychology and rehabilitation to explore. Since that time, we have seen the development of VR systems that have demonstrated added-value for addressing a variety of clinical conditions and research objectives including: fear reduction with phobic clients, stress management in cancer patients, acute pain reduction during wound care and physical therapy with burn patients, treatment for Post Traumatic Stress Disorder, body image disturbances in patients with eating disorders, navigation and spatial training in children and adults with motor impairments, functional skill training and motor rehabilitation with patients having central nervous system dysfunction (stroke, TBI, SCI cerebral palsy, multiple sclerosis, etc.) and in the assessment (and in some cases, rehabilitation) of attention, memory, spatial skills and executive cognitive functions in both clinical and unimpaired populations. To do this, scientists have constructed virtual airplanes, skyscrapers, spiders, battlefields, social events populated with virtual humans, fantasy worlds and the mundane (but highly relevant) functional environments of the schoolroom, office, home, street and supermarket. These efforts are no small feat in light of the technological challenges, scientific climate shifts and funding hurdles that many researchers have faced during the early development of this emerging technology.

So where have we been and what do we have to look forward to with a technology that shows no sign of withering on the vine! What has worked so far and where have we hit a wall? How has mainstream clinical thinking about VR changed over the years since Lawnmower Man, DisneyQuest or Dactyl's Nightmare? This ICDVRAT 2008 Keynote will provide a summary of the past in counterpoint to a brief review of the future. Where illustrative, examples of VR applications dating back to the 20th Century will be discussed along with an update as to where they are now and what might be in store for the future as the 21st Century continues to pick up steam! At worst, the talk will be a nostalgic walk down VR memory lane coupled with some harebrained schemes for the future. At best, it will be an insightful summary of what we have learned so far, and how that can be used to inform a realistic roadmap for how VR can positively enhance the future of clinical care and research!

2. WHAT HAS CHANGED?

2.1 Expansion and Evolution of Clinical VR Applications

Over the last 10-15 years, we have seen significant advances in both the technology and the thinking that supports Clinical VR application development. As the field has matured, a number of forces have converged to support the creation and evaluation of VR systems that have gone well beyond its entry "showcase" application area in exposure therapy for anxiety disorders. At that time it was quite natural that exposure therapy was the first area to find value in a VR delivery mechanism. In the mid-1990's, VR technology was still quite costly and knowledge of 3D-interaction methods and user interface design was scant among those interested in the clinical use of VR. However, exposure therapy applications were less challenging to develop since the interaction requirements were relatively minimal, and much to our surprise, the graphics didn't have to be exact replicas of reality to produce the desired level of anxiety arousal needed to support the therapeutic process of habituation. Early patients treated with VR for acrophobia were observed to approach very graphically limited "Indiana Jones" style plank bridges perched over deep ravines and were so "primed" for fear of such conditions that the necessary level of anxiety arousal was sufficiently present to begin to apply exposure therapy methods. Soon it was found that with repeated exposures to such cartoonish imagery, patients would show subsequent extinction of the fear response and that these reductions would carry over to the real world. Hence, the field of clinical VR was jumpstarted from successful systems that gave courage to the fearful!

Shortly thereafter, VR-dedicated companies such as Virtually Better, Inc. began to emerge from the union of Computer Scientists (i.e., Larry Hodges) and Clinical Psychologists (i.e., Barbara Rothbaum) driven by the early vision of creating such VR exposure systems for this slice of the clinical population. At the same time, other scientists and clinicians began to create alternative visions for how this "cool" technology could be used for the assessment and rehabilitation of cognitive/motor dysfunction in an ecologically valid and sometimes more motivating fashion. Although when compared to exposure therapy approaches, the technical requirements for tracking motor behavior and fostering natural interaction within virtual worlds were a bit more demanding in these areas, many of the primordial efforts to address those challenge started to appear at events like Medicine Meets Virtual Reality (MMVR) and the European Conference on Disability Virtual Reality and Associated Technologies (ECDVRAT) in 1996 (later changed to the ICDVRAT in 1998, to better reflect the growing International nature of the field!). Applications by Giuseppe Riva next emerged to provide body image visualization for those with eating disorders, shortly followed by Hunter Hoffman's seminal work with VR for pain distraction, which opened up a completely novel and important clinical application domain that somehow was missed by those who had come before! These historical clinical-conceptual events, in combination with the ever-accelerating growth in computational speed and power, set the stage for the birth of a VR application area which in reality could actually trace it conceptual roots back 70 years to the tinkering of an organ builder in Binghamton, New York (Edwin Link) leading to the creation of the first aircraft simulator – the Link Trainer.

2.2 The Past Sets the Stage for the Future

So by the start of the 21st Century, all the pieces were in place for the vigorous evolution of a new field of clinical and research science, all based on leveraging the core VR attributes that had been recognized during the early years as well matched to the needs of various clinical targets. In this regard, a growing legion of clinical scientists began to see VR, not so much as a Sci-Fi dream, but rather as a usable tool, that when wielded by the hand of a well-trained clinician, could enhance elements of exposure, distraction, motivation, visualization and measurement beyond what was available with the methods of the past. Since then, the field of VR has continued to expand to address a diverse range of clinical conditions and scientific questions that stand in stark contrast to what was being done a mere ten years ago. So what else has changed in the last ten years to make this all happen? In this one hour Keynote, I will try to briefly address what has changed the VR landscape over the last ten years and attempt to make some speculations about where we may be heading in the next 10!

Here follows just a few teasers …

- *Computational Speed and Power* – During the late 1990s, computing and graphics technology had advanced to the point where basic PC systems with new more powerful graphics cards could begin to serve as computational platforms for delivering immersive VR. Gone were the days of $200,000 Silicon Graphics reality engines that kept VR in the realm of research labs, out of reach of everyday clinicians. These advances in computing prowess were predicted indirectly in 1965 by Intel co-founder, Gordon Moore, who wrote a paper for Electronics Magazine predicting that the number of transistors that could be placed on an integrated circuit would double every two years. Although some say that this exponential increase (Moore's Law) occurs every 18 months, the end result has allowed for affordable processing power to meet the needs of innovative VR researchers. This continuous and predicted growth in processing power had finally balanced the VR expectation-to-delivery ratio that had previously hamstrung the imaginative visions of those in the field in the 1990's!
- *Game Industry Drivers* – There is no doubt that the recent growth in the interactive digital game industry arena will continue to drive developments in the field of Clinical VR. The gaming industry juggernaut's growth is evidenced by the fact that as of 2002, it had surpassed the "Hollywood" film industry in total entertainment market share, and in the USA – sales of computer games now outnumber the sale of books. And this digital "gold-rush" has driven technology and social developments well beyond early expectations. The impact of this can easily be seen in the areas of graphics techniques and horsepower, display technology and in the creation of novel interface tools, the evolution of which was directly driven by the economic growth of the game industry. Just one example of the game industry's impact on graphics – the original SONY PlayStation, released in 1995, rendered 300,000 polygons per second, while Sega's Dreamcast, released in 1999 was capable of three million polygons per second. The PlayStation 2 rendered 66 million polygons per second, while the Xbox set a new standard rendering up to 300 million polygons per second. Thus, the images on today's $200 game consoles rival or surpass those available on the previous decade's $50,000 computers. This is Moore's Law in overdrive when big money and market enthusiasm is on the line!
- *Graphics Hardware and Software* – In large part due to the economic drivers in the game industry, massive advances in graphics have pushed the field almost beyond the level where the term "graphic realism" really captures the point. By contrast, a more apt descriptor could soon be graphic unrealism! Such hyper reality can be seen in some of the latest offerings from the game development company Crytek. In their recently released version of the game In Crysis, a new level of graphic expression has been reached. A demo video from this group will be presented during the Keynote to back up this claim. However, while the game industry drives the latest and greatest to feed the public craving for better entertainment options, eventually this level of software filters it way down to content available in the Clinical VR domain. Perhaps one of the best examples of this is with the open source game engine "Ogre". Examples of this tool will also be presented during the Keynote. Finally, perhaps the most useful piece of software for the interests of our field is Giuseppe Riva's milestone (and free!) software tool called NeuroVR. Designed for folks who want to build virtual worlds without a degree in computer science, this tool gives you "starter" environments of many archetypic worlds relevant for Clinical VR and provides fairly usable options for modifying them to meet the unique needs of a wide range of applications.
- *Display Technology* – The eMagin head mounted display (HMD) and similar low cost options have now made this form of immersive VR accessible within the budgets of clinicians and fledgling VR scientists. With the advent of an integrated tracking solution with bright Organic Light Emitting Diode (OLED) displays, this HMD is now the workhorse of Clinical VR. Advances in stereoscopic flat panel displays and autostereoscopic system are also continuing to provide new displays options for applications where full immersion is not required, particularly in upper extremity motor rehabilitation and for cognitive assessment.
- *Low-Cost Interaction Devices* – Lower cost hardware is supporting this area and the big news comes in the form of low cost camera-based optical tracking solutions to support interaction methods. While there will always be a place for robotic and high end optical tracking systems (e.g. Immersion Corp., the Motek "Caren" system) for well-heeled clinical centers, a number of labs are now using off the shelf web cams to track upper and lower extremity movement that is embedded in game-like contexts for motor rehabilitation. And of course the Ninetendo Wii has engaged the public consciousness, driving SONY and Microsoft to take notice that humans do occasionally like to naturally interact with their game content. As well, the Wiimote interface has generated a buzz for its elegant simplicity as a 3D user interface and has been hacked for a variety of creative applications. However, a general word of caution is in order here. While a lot of groups like to bandy about terms like "Wiihab" and "Wiihabilitation", and in fact the Wiimote has shown value as an exergaming interface, to refer to any

activity afforded by an interface device as rehabilitation is misguided and requires a bit more thought. Rehabilitation tasks need to meet specific criteria and while it is easy to train flailing with a Wiimote, genuine motor rehab requires clear knowledge and specification of the target to be trained to inform the choice of interaction method and task design required to support precise motor action, albeit in a fun and engaging game context. Finally, while overshadowed by the excitement surrounding the Wii, the Novint Falcon force feedback system now offers a new set of options for game-based rehabilitation at a cost of less than an IPOD!

- *Virtual Humans* – As the underlying enabling technologies continue to evolve and allow us to design useful and usable "structural" clinical VR environments, the next important challenge will involve "populating" these environments with believable virtual representations of humans. Over the last ten years, the technology for creating virtual humans has evolved to the point where they are no longer regarded as simple background characters, but rather can begin serve a functional interactional role. More recently, seminal research and development has appeared in the creation of highly interactive artificially intelligent (and natural language capable) virtual human (VH) agents. No longer at the level of a prop to add context in a virtual world, these VH agents are being designed to perceive and act in a 3D virtual world, engage in face-to-face spoken dialogues with "real" people and other VHs in such worlds, and they are becoming more capable of exhibiting human-like emotions. Previous classic work on virtual humans in the computer graphics community focused on perception and action in 3D worlds, but largely ignored dialogue and emotions. This R&D will likely figure prominently in the dawn of "VR 3.0" and will be found to be vital in the creation of clinical training tools that leverage the use of VHs for clinical applications that address interviewing skills, diagnostic assessment and therapy training.
- *Psychophysiology and Imaging* – there is a rather compelling rationale for the integration of VR with human physiological monitoring and brain imaging for advanced research and clinical application. There exists a rich history of research in the disciplines of psychophysiology and neuroscience where the technology for recording bodily events in the least invasive fashion possible has evolved in order to capture and understand correlates of human mental and/or physical activity. Examples of such efforts would include the measurement of skin conductance, heart rate, electrical brain activity (electroencephalography), and brain structure and function (e.g., fMRI, DTI, SPECT, etc.) while a person attends to emotionally laden or cognitively challenging stimuli. While these monitoring technologies have existed for some time, the stimulus delivery media has remained essentially the same for many years, relying mainly on precisely delivered fixed audio and visual content. Although sophisticated display formats have been used in psychophysiology (i.e., tachistiscopes, projection systems, flatscreen computer monitors, etc.), these systems put significant constraints on naturalistic human behavior and interaction that may be relevant for studying research questions on integrated functional performance. The use of VR now allows for the measurement of human interaction within realistic dynamic 3D content, albeit within the constraints of the monitoring apparatus. The strength of VR for precise stimulus delivery within ecologically enhanced scenarios is well matched for this research, and it is expected that continued growth will be seen in this area. Such growth will likely occur with new Bluetooth enabled portable monitoring devices (e.g. Lifeshirt, Emotiv, Emsense) and with recent developments in the functional near infrared spectroscopy (fNIRS) area.
- *2nd Life and Beyond!* – While overwrought popular media exposure has caused 2nd Life to bounce around the Gartner Group Technology "Hype-cycle", alternating between the peak of inflated expectations and trough of disillusionment, there is no denying that internet-based social networking VR worlds that allow for avatar embodiment will continue to grow and have some impact on clinical care. Thus far, 2nd Life (and other similar worlds) have shown some value as a space to disseminate health and educational information, deliver some level of training and to provide gathering points for support group activity with clinical populations (e.g. stroke, TBI, Aspergers, etc.). The next questions to consider will involve an honest assessment of both the ethics and efficacy of using these spaces for the provision of clinical care.

These are just a few of the topics that I will attempt to concisely address in the ICDVRAT2008 Keynote and I thank the conference organizers for offering me this opportunity to spend some time sharing my views on how the past may inform the VR future! Space limitations preclude a full detailing of the references for what I have described above, but at the conference, I will make available a handout of all the references for the work cited. All references will also be made available on the ICDVRAT Archive.

ICDVRAT 2008

Keynote II

Robert Astur *on* Brain Imaging and Psychological Disorders

Chair: Patrice L (Tamar) Weiss

Functional Magnetic Resonance Imaging (fMRI) and virtual reality: adding brain imaging to your virtual reality repertoire

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1. INTRODUCTION

Investigating the neural bases of human behavior is a remarkably complex process. In the 20th century, the traditional tools available to researchers have typically involved studying behavioral changes following a brain injury or lesion, as well as a number of physiology measures such as recording and stimulating brain areas (either inter-operatively or chronically during medical telemetry, often implemented to localize epileptic foci). Each of these has made unique contributions in providing insights into brain and behavior relations. However, such studies are invasive, and are not ideal for most purposes.

Within the last couple of decades, a variety of noninvasive brain imaging techniques have been developed and implemented to add to the arsenal of tools available to study brain function. Most notably, functional brain imaging has emerged as a method to examine correlates of brain activity. The term "functional brain imaging" typically refers to any technique that examines brain function noninvasively such as functional magnetic resonance imaging (fMRI), positron emission tomography (PET), electroencephalogram (EEG or event-related potentials – ERP), magnetoencephalography (MEG), or near infra-red spectroscopy (NIRS). For the purpose of this paper, the focus will be on fMRI because most of the problems and solutions that apply to fMRI will generalize to any of the other techniques.

This paper is designed for the VR researcher who has interest in using functional brain mapping during VR research, but who is unsure of the various issues that are involved in such a venture. Included are some of the main factors that one should consider in starting VR/fMRI experiments, and common solutions to problems that arise are provided. This primer can be used by anybody, ranging from the new graduate student with no research funds available to a full professor with generous available funds and unlimited staff.

2. SCANNER

The first item necessary is a scanner. An fMRI scanner is no different than the standard MRI scanner found in most hospitals. In fact, most scanners are used interchangeably to do both MRI and fMRI. The difference between the two is that for standard MRI, the scanner is tuned to be sensitive to hydrogen concentrations, which results in excellent resolution of anatomical structures. For fMRI, the same scanner is tuned to be sensitive to oxygen use, which results in excellent resolution of areas with oxygen, such as the blood.

Most new scanners have built-in software that allows the user to choose the type of scan they want, so knowledge of MR sequences is not always necessary. However, it always will be valuable to have an experienced collaborator or MRI technician to recommend optimal settings for the scanner and for the experimental protocol. But, without those collaborators, one still will be able to collect good data, even if it is not optimal data. For optimal data, it is ideal to be in a situation where an MR physicist is available, or to be in an environment where optimized protocols already exist. Furthermore, every publication should have detailed information on scanning parameters, so simply reading a paper which used desired scanning techniques often will be sufficient for obtaining the correct scanning parameters.

If you are at a place where no functional brain imaging is being performed, but yet they have an MRI machine, the best bet is to meet with the Director of the MR center and ask about performing functional imaging. A large majority of places are performing functional imaging, even if their scanning is not of the brain (e.g. cardiac or prostrate are common ones). By expressing your interests to the Directors at such a center, they may be willing to move into brain imaging as well. It is not overly difficult to move from one type of imaging to brain imaging, but the support of the Director and a MR technician will be necessary for it.

3. HARDWARE

The major hardware constraint during fMRI experiments revolves around the fact that the MRI machine is an extremely powerful magnet. A 3T MRI scanner is 60,000 times stronger than the earth's magnetic field, so iron materials must be avoided during MRI scanning. The majority of over-the-counter gaming / VR hardware almost always contains some iron, whether it is screws, springs, or motors, and any device with iron can be drawn to the magnet with incredible power and speed which could damage the scanner and create a deadly accident for the participant.

The solution for these problems can be relatively simple. To detect whether a piece of hardware has iron, the simplest way is to run a small hand magnet over the hardware to detect where the iron is located. If the iron is a screw or spring, these typically can be replaced with plastic substitutes that can be bought easily either online or at a local hardware store. For larger iron pieces, such as a force-feedback motor, the options are much less apparent, and the experimenters should ask themselves whether that hardware feature is absolutely necessary for the experimenter.

Alternatively, there are a number of companies that now sell MRI-compatible interfaces such as joysticks, trackballs, and keypads. These products often utilize fiber optic technology and work well. The downside is that these often are quite expensive, about $1500 USD for a joystick, and are fragile.

In our lab, it has proven most effective and cost- and time-efficient to cannibalize an over-the-counter product to work in an MRI environment. When we were designing steering wheels and gas/brake pedals for the scanner, we sought quotes from a few companies, and each quote was well over $10,000. Eventually, we settled on buying a $40 Logitech racing wheel and replaced the metal screws and springs with plastic ones, for an additional cost of about $100. Another steering wheel system using the same Logitech wheel has been made MR-compatible by replacing the springs with thick rubber bands, collectively costing us about $200. Hence, there are numerous alternatives to spending thousands of dollars on MRI-compatible hardware.

Lastly, whereas iron is problematic and dangerous in an MR environment, this is not the case with all metals. Aluminum and copper (and other metals) can often be used where metal is absolutely necessary. The two main issues with a substitute metal are that certain metals can heat up from the radio frequency signal during scanning. The 2nd problem is that the metal may create artifact in the brain imaging signal, so that the brain imaging data are unusable. Both of these can be tested out without a participant being in the scanner to assess whether these problems arise.

4. VISUAL DISPLAY

For all VR scenarios, it is critical to have a good visual display. However, the visual display issue during fMRI is not as complicated as one might think. Because the participants cannot move their head during a brain scan, most advantages of the standard HMD are no longer relevant. For example, head tracking is a moot point when the participant cannot move their head, so the display typically can be reduced down to having a projection screen and an LCD projector. In this case, there is a projection screen either below or above the participant's body, and the image is displayed on the screen from an LCD projector; the participant views the screen with 45 degree mirror glasses. An alternative is to purchase fiber optic goggles that can be used. However, fiber optic goggles can be quite expensive, possess lower resolution that an LCD projector, and are difficult to fit in the MRI scanner, depending on the size of the scanner opening and the head coil. Nonetheless, if one is interested in presenting different visual images to each eye, fiber optic goggles are the one of the only solutions.

5. SOFTWARE

The major issues in software design revolve around providing relevant information for analysis. Often during the analysis stage, it is valuable to the experimenter to have a software marker that would link critical events in the VR scenario to the brain imaging data. For example, if a rare event occurs in the VR scenario, such as a car accident, it might be of interest to examine the brain-related changes linked to this event. Given that such events occur unpredictably (it would depend on how fast the participant is driving, where they are in the environment, etc), there is no *a priori* way to know how to link the behavior with the brain imaging data. Stated another way, there would be no way to know which brain images, within a large stream of brain images, are the images of interest. To address this, software simply needs to put out markers to a data file of when important events occur, so that this later can be linked to the brain imaging files, and the appropriate analysis can be conducted. This is a simple thing to do for groups that have access to the source code for their software, but would prove difficult when using over-the-counter software that is not easily modified.

6. FEASIBILITY

Even with the proper software and hardware, it may prove difficult to conduct a reasonable fMRI experiment. Most institutes charge a hefty fee for scanning, typically about $500/scan, so that a simple study with 20 participants costs $10,000, without considering software, hardware, analysis, and participant reimbursement costs. There are, however, a few ways to negotiate these expenses. Aside from getting grants, numerous institutes have "Pilot Study" grants, where 10-20 free scans are given to a researcher in order to collect enough pilot data to submit a grant with funding for a larger imaging study. Such "pilot study" mechanisms are rarely detailed at an institute's website, but they are quite common.

Alternatively, another way of acquiring free scans is to meet with the director of the center and express your interest in obtaining some pilot data for your dissertation, future grant, etc. Most people are sympathetic to newcomers in the field and will allow some free scanning. Note that your chances of obtaining free scans will be dramatically improved if you present a well thought out plan on how these data will be used to acquire funds for future scans. Because of the huge cost of a scanner, imaging centers are typically always watching their budgets, and they are pleased when researchers are able to bring in funds specifically ear-marked for scanning.

For graduate students, an excellent way for free scans is to ask the director (or similar higher-level researcher) of the imaging center to be on your dissertation committee. Another productive method is to ask a researcher who is scanning if you can add a short task onto their scanning protocol. Effectively, that researcher is paying for the scans, and you are using 10-15% of their scan time as your own. Of course, you'll want to engage in some sort of barter system with this researcher; for example, discussing co-authorship on your publications, or perhaps sharing software or programming with their lab. In my experience, if some or all of these techniques are attempted, almost anyone can start some scanning without any funding.

7. ANALYSIS

Collecting good data is only the tip of the iceberg. The analysis portion can be simple or very complex depending on design and theoretical constraints. For somebody with grant support, imaging centers often have people who will analyze the data for you, and who will summarize it nicely for you with figures and written text. These people are a wonderful asset to any project, but they can be costly, and you will forever be dependent on such individuals unless you know how to analyze data by yourself. An alternative way is to meet with somebody knowledgeable about analysis that will show you how to analyze the data. This will be more time-consuming and frustrating in the beginning, but you will quickly become more independent and learn analysis techniques with this method.

Critically, there often are divisions on how best to analyze data and which software to use to analyze it etc. Avoid these traps! It is easy to spend years debating such issues which really are not relevant to your experiment. Find some published papers that you admire, examine their analysis techniques, and try to adopt something similar. For many of the popular analysis software (SPM, AFNI, Brain Voyager), there are wonderful websites, blogs, and help options available where users can post questions and receive reasonable answers.

8. DESIGN

Lastly in any research project, there never is a substitute for good experimental design. A large amount of time should be spent on the design of the experiment, including having a very specific idea on how the data will be analyzed. This can be daunting (particularly the analysis part), and the best way to address this is to consult with experts in your field via email or in person about how best to design the study. Brain imaging has many projects designed with questions such as "What activates in the brain when somebody does X?"

Such approaches devoid of theory and *a priori* hypotheses almost inevitably result in poor design, poor analysis, and worse interpretation. As in any study, the design should be constrained and shaped by related studies, even if they are not VR- or brain imaging based.

9. SUMMARY

In summary, VR can be used during brain imaging if some appropriate steps are taken. As in all scientific endeavors, probably the best way to learn and implement any new technique is find a knowledgeable and respected researcher and seek their advice for your specific interests. Without such a person, a motivated individual still can integrate brain imaging into their experiments using some of the advice detailed above, but it will take a bit more legwork and perseverance. Nonetheless, integrating VR and brain imaging can be a valuable tool for understanding the neural basis of realistic behaviors.

10. SAMPLE ARTICLES INTEGRATING VR AND FMRI

Translational article combining fear conditioning in VR environments with fMRI.

R P Alvarez, A Biggs, G Chen, D S Pine and C Grillon (2008), Contextual fear conditioning in humans: cortical-hippocampal and amygdala contributions, J. Neurosci., 2008 Jun 11;28(24):6211-9.

Technically difficult experiment with steering wheel, pedals, and VR during fMRI.

K N Carvalho, G D Pearlson, R S Astur and V D Calhoun (2006), Simulated driving and brain imaging: combining behavior, brain activity, and virtual reality, CNS Spectr., 2006 Jan;11(1):52-62.

Excellent use of custom VR goggles for fMRI use and stereoscopic visual presentations.

H G Hoffman, T L Richards, J Magula, E J Seibel, C Hayes, M Mathis, S R Sharar and K Maravilla (2003), A magnet-friendly virtual reality fiberoptic image delivery system, Cyberpsychol. Behav., 2003 Dec;6(6):645-8.

Standard spatial memory assessment during fMRI using VR and joystick.

S L Shipman and R S Astur (2008), Factors affecting the hippocampal BOLD response during spatial memory, Behav. Brain Res., 2008 Mar 5;187(2):433-41.

ICDVRAT 2008

Interpretations (Casa da Música)

Chair: Paul Sharkey

Interpretations: an inter-sensory stimulation concept targeting inclusive access offering appreciation of classical music for all ages, standing, & disability

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ABSTRACT

'SoundScapes' is a body of empirical research that for almost two decades has focused upon investigating noninvasive gesture control of multisensory stimuli and potential uses. Especially targeted are disabled people of all ages, and a special focus on the profoundly impaired who have limited opportunities for creative self-articulation and playful interaction. The concept has been explored in various situations including: live stage performances; interactive room installations for museums, workshops, and festivals; and in healthcare sessions at hospitals, institutes and special schools. Multifaceted aspects continuously cross-inform in a systemic manner, and, in line with Eaglestone & Bamidis (2008), each situation where the motion-sensitive environment is applied is considered as a hybrid system. The presented preliminary work exemplifies the motion-sensitive environment and how it is used to elicit dynamic performance data from a situation that features the Orquestra Nacional do Porto. A goal is to complement the music by offering an experience of inter-sensory stimulation. Inclusive access is planned in order that all may have an opportunity to appreciate classical music. This paper reports on the background, the targeted experience, and future plans of the concept.

1. INTRODUCTION

'SoundScapes' is recognised as a motion-sensitive environment (MSE) and each situation where it is used is considered as a hybrid system consisting of networks of complex inter-connected subsystems comprising 'created technical systems' and 'natural human systems' (Eaglestone & Bamidis 2008, p. 19). The dynamic relationships between these systems facilitate inter-sensory stimulation and this is a focus of the created preliminary research situation that features Orquestra Nacional do Porto at Casa da Música, 11th Sept 2008.

SoundScapes has been explored in various situations over two decades. These include live stage performance, interactive room size installations/workshops at museums, and in healthcare – specifically with profoundly disabled people in 'therapy' sessions at institutes, hospitals or special schools. Each situation is considered as an Inhabited Information Space (Brooks in Snowdon et al. 2004), and this perspective contemporizes and integrates the earlier work such as Virtual Interactive Space (VIS) (Brooks 1999). The next sections present examples of the background and history from prior art and design perspectives. Many of the design issues will be implemented in the Porto preliminary research session demonstration.

2. CHOIR 1999

'The Circle of Interactive Light' (COIL) exhibition (Brooks 1998–1999, *video link*[1]) was a situated hybrid system consisting of a large multisensory interactive room installation – (VIS) – comprising multiple robotics, projections, image manipulations, music, effects and interactive sculptures that were affected via data being captured from people inhabiting the space via the motion-sensing technical setups.

The COIL toured leading Scandinavian Museums of Modern Art to approximately a reported 1.5 million people. The COIL exhibit resulted in contact from the Danish national TV and the European Film School, and following a jointly conducted survey that found a decline in classical music TV audiences, a

SoundScapes presentation and workshop was hosted at the European Film School to conceptualise solutions. A resulting situation was agreed where the author was invited to exemplify his concept in using complementary visuals with classical music where the image had a real-time relation to the live performance. A choir was recorded at the DR national TV in studio 12 and an interactive solution was tested (*video*[2]).

In designing for classical music I restrict the sensory digital feedback manipulations to non-auditory, in other words, I do not wish to affect the music so the focus is mostly on visual interpretation. In the case of a choir it is only their mouth and facial expressions that move. Therefore the focus is on the conductor as he is engaged throughout each piece and continuous motion is present. In this case he was requested to arrive early at the studio to test the system. He also agreed to wear a white paper overall that is sold for protecting clothing when painting. This enabled projections from behind to blend him into the multiple projection collage. Projections were from behind to include his shadows so that change of animation colour could be related to his hand gesture by the TV audience, especially when the selected broadcast camera angle did not show him in person. The animations were created as geometric stained glass window effects according to the 'gothic' feel of the music with a software programme called Bliss Paint[3] for the Apple Macintosh. Real-time interaction was via the conductor's gesture within three invisible volumetric zones emitted from a noninvasive infrared sensor (see figure 1). 'Digital animations' were improvised in real-time onto the white outfits that were worn by the choir members. The comments from the conductor of his experience align with the use of SoundScapes in rehabilitation training, i.e. an empowered unconscious augmentation of motivated movement (Brooks 2004, p. 104). Access to the choir broadcast was made available online (*video*[2]) and the result was an invitation from New Zealand artist Raewyn Turner who associated the work to her multisensory concept titled Four Senses which featured an Auckland youth orchestra. I accepted as I had not researched olfactory before or been to New Zealand and the commission was appropriate.

3. ORCHESTRA 2002

An important initial period of artist-artist 'getting-to-know-each-other' through presenting works, techniques and methods was followed by the build of the MSE (which involved sponsorship meetings, PR etc.,). The meeting of the team included the 'Aotea Youth Symphony', conductor, director, film crew, and supporters (*see online*[4]); the mixed ability dance company 'Touch Compass' led by Artistic Director Catherine Chappell (*see online videos*[5,6,7]), deaf signing choir, 'Hhands'; and sight-impaired vocalist, Caitlin Smith[8]. On the technical side the lighting rig supplied by Kenderdine Electrical was Martin Lights and included MAC 600™, MAC 2000 Profile II™ and their LightJockey 2™ (*technical review online*[9]). Tactile devices were Aura Interactor cushions and large balloons to hold in the fingers by the deaf audience members.

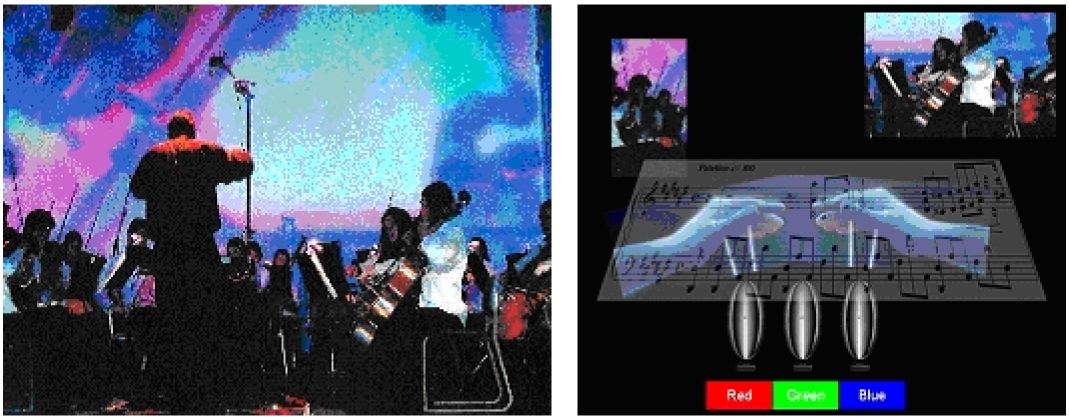

Figure 1. *New Zealand – Four Senses: Conductor is the main generator of motion data from within three infrared sensor zones that are mapped to Red, Green, and Blue animation sequence filters.*

Movement was taken from various sections of the orchestra – 3 x SoundScapes infrared sensors controlled an animated Red, Green, and Blue image filter system (figure 1). This was set up so the orchestra conductor's hands digitally painted as he moved so that he could digitally paint the floor to ceiling screen images on the back of the stage (see figures 1, 2 & 4). Images were selected and blended on the fly. A video-feedback system with double video camera enabled an analogue input to the image mix. Microphones captured the music from stage with the dynamic data used to manipulate images. Five static video cameras were setup on various stage performers (see figure 4). Three mobile video cameras with operators were instructed via a communication network of headphone/mic walkie-talkies. These various stage signals served a switching bay that was created with a bank of video monitors to observe image signals. Downstream were video mixers which then served 5 computers (Mac & PC) and following a final manipulation of the material it was blended to feed seven powerful projectors that were sponsored by Epson New Zealand. A sizable foyer installation was additionally setup on large bubble wrap where a “mini performance” featured the Touch Compass dancers triggering/controlling their own video image feedback & sound via the sensor/camera system. A sponsored Epson printer enabled shots of the dance to be printed and freely given to the audience.

Figure 2. *New Zealand – Four Senses: Aotea Youth Symphony and Touch Compass dancers generate inter-sensory stimulation data to affect the experience of classical music for deaf audience members.*

Pre-programmed light states were integrated into a lighting plan and a pc based stage-lighting program to make multiple sequences and cues for use in improvisation. In the performances improvisation took place within the bounds of the lighting states and smells created for each piece of music. Lighting change had an added dynamic as camera image software, being sensitive to lumen change, “exploded” and reset to an adjacent hue in the colour-chart. This was a wonderful find and promoted the eventual light performances to be mostly improvised in real-time as the computer programming was found to be too restrictive as subtle changes from one of us affected the other’s input, so there was much talking on the headsets for timing etc. The orchestra was dressed in white and under lit with ultraviolet light to provide an image canvas. Divided into sound groups, each section was assigned a colour and it’s complimentary to achieve high degrees of retinal stimulation, brightness, and afterimage. The efficient dispersal of smell was important to the comfort of a ‘closed room’ audience. Processed by an industrial chemist into aerosol sprays, they were applied direct to the air conditioning system which distributed the fragrances evenly through the auditorium on cue. The fragrances were mixed/cleared away using the air conditioning fans in the building. Warning notices were posted with the advertising of the event, informing audiences of the presence of smell. The computer software used was various image processing algorithms mapped to affect the eight stage camera feeds. Blended output was into live performance programs installed on the three upstream video mixer computers with the final composition through real-time improvisation manipulation of parameters of Eyesweb. The main output software algorithm was one that I initiated and supervised the creation of in Lund, Sweden, as a part of the European project called CARE HERE (Brooks & Hasselblad 2004). This ‘bodypaint’ algorithm is offered in the Appendix with notes regarding use in the Porto offering. Various other aspects of the New Zealand performances are reported via Turner (2003); Brooks (2004); Prime time TV documentary (*videos*[10,11,12]), and other online resources[13]. Direct information on the Four Senses is available from the Aotea Youth Symphony director and conductor detailed at the concert online link[14] and the orchestra web site.

4. SOUNDSCAPES: GENERAL CONCEPT – REVIEWED

As its name implies and examples illustrate[15], SoundScapes is focused upon multisensory stimuli and specifically design, translations, and intervention, especially of auditory and visual feedback (including Virtual Reality – see example online[16]). It has been used mostly with human participation but other life forms have been explored (see example online of fish painting as they move to the music[17]). Control data is mostly generated via free unencumbered reactive gesture. A selection of noninvasive input devices are used to capture various human 'feedforward' data that is mapped via a computer workstation to control immediately experienced selected multimedia. The multimedia can be selected from libraries of responsive content and adaptively programmed to suit participant(s) and situation. The manipulated audiovisual mediums are then delivered to be experienced by a speaker system (auditory) and/or a large screen (visual).

Usually, the design is such that the originator of the gesture experiences the sensory stimuli that is under his or her control and reacts accordingly with a suitable reactive gesture. This has been used in rehabilitation training and a patented marketed product realised. Findings show how feedback content design, input device programming, and physical setup can be prepared, adapted and later refined to stimulate specific feedforward targeted action. In all cases, the human's afferent-efferent neural feedback loop is suggested closed[18] and a cyclic stimulus-response chain established (Brooks et al. 2002).

According to the specific situation and the profile of the participant(s) and/or audience, decisions are made whether innate design parameters of response manipulation should be directed toward targeting a goal via the feedback content design, the input device programming, or input device physical setup. Alternatively a less complicated, freer content may stimulate the desired goal reaction without calibrations etc. In the preliminary stage of the research presented on this occasion we target an abstract interpretation where performance data controls the audience visual experience. Figure 3 illustrates the spectacular auditorium which is the venue where the situated opportunity to create for Orquestra Nacional do Porto will take place.

Figure 3. *Main auditorium and venue for the event at Casa da Música, Porto. ©Casa da Música.*

5. SPECIFIC CONCEPT

The VIS design that is proposed for Orquestra Nacional do Porto differs from my previous commissions at Casa da Música as the gesture originators are the musicians/conductor who are, for the most part, required to focus on the score. Also the strict structure of the musical form prevents musician distraction, e.g. changing articulation according to visual stimulus change. This design then approaches the Danish choir and New Zealand orchestra performances as in such contexts the musicians and conductor are not able to fully experience the visual feedback as may a jazz improviser who could interactively 'play the images'. Thus the orchestra role is maintained as the traditional mediating tool between the composer of the music, the agreed interpretation, and the audience. The receiver in this situation is the audience with the mixer operator as their visual experience facilitator. In a fashion this resembles the facilitator role in the therapy situations.

In a sense this diminishes the problems experienced with camera latency and real-time interpretations as unpublished tests have shown how problematic this is for a trained musician to accept the temporal change associated to the visual stimulus delay.

To date the greatest success has been with using the infrared input device as opposed to camera in respect of real-time motion data captured-to-motion data visualised in 'real-time'; this is also the case where a defined field of interaction is desired as it is problematic to isolate depth of camera field from an activity that is setup parallel to the camera. Complexity of camera/graphics processing algorithm can also affect the latency. However, a balance is always targeted in the improvisation to offer audience association to where the data is captured from so that the image manipulation can be related. The data processing is also planned to affect the stage lighting via advancement to the Eyesweb algorithm (see Appendix) such that a direct link to the selected performer enables lighting change. This feedback loop between light and camera could have an adverse effect and thus the design incorporates a 'get out strategy' to bypass. No two performances are alike.

6. CASA DA MÚSICA SETUP

Data is sourced from the Orquestra Nacional do Porto live performance via a network of infrared volumetric sensors and CCD video camera sensors (figure 4). Microphones are also used to capture the music. The data is collected and monitored at a mixer station where mapping decisions are made in improvised visual collage creation which is projected on stage located floor-to-ceiling screens. Balloons are used for the audience to hold lightly in their finger tips to experience the dynamic vibroacoustic sonic properties of the music.

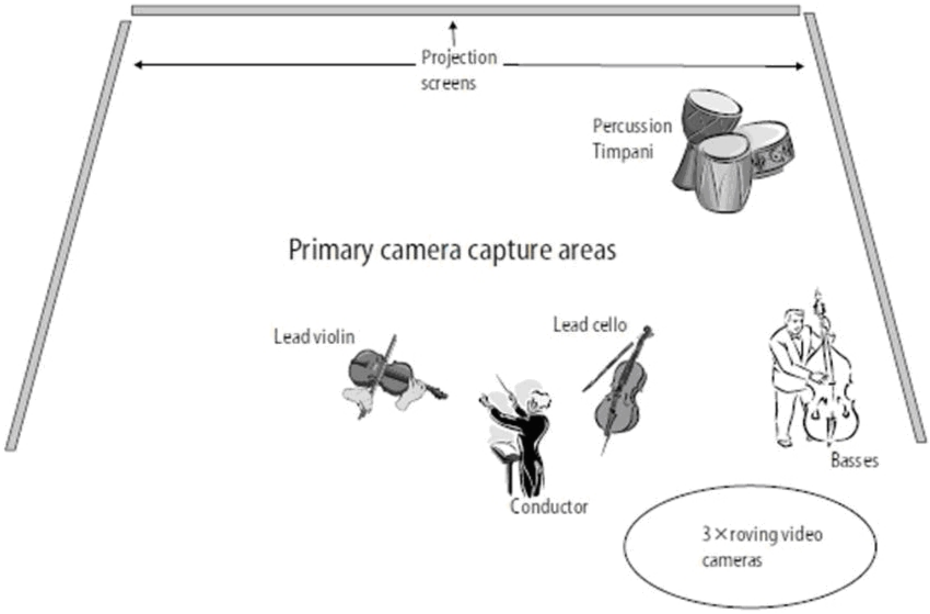

Figure 4. *Proposed stage capture area of data – Orquestra Nacional do Porto.*

7. TARGETED EXPERIENCE

The main auditorium in Casa da Música should be a spectacular venue for realising the eventual proposed inter-sensory event and time spend to experiment with the physical environment will be precious. Figure 3 illustrates the dynamic 'gold' wall patterning that should be responsive to dynamic light effects, Figure 5 illustrates the stage area overhead screen, the rear of audience area screen, and the end walls glass feature. The featured pieces will be 'Zapping' by Tinoco, and Symphony number 4, finale, by Nielsen.

It is appropriate that the 2007 RIBA award-winning concert hall and arts venue Casa da Música that stands on Rotunda da Boavista in Porto, Portugal, and which was funded through the European culture capital 2001 is hosting this event. It is also fitting as 'the generation of an effective environment with aesthetic resonance' was one of Rem Koolhaas' architectural concepts. Casa da Música has also been designed to address the relationship between the concert hall and the public by targeting involvement of the majority rather than a select minority. In-house departments focus on this by organising events and happenings to attract audiences and participants from all walks of life. This inclusive strategy is no more prominent than when annually in April workshops and public performances are conducted that feature disabled people. This bringing home to all that attend that all people are creative and all people have a right to express their creativity.

Figure 5. *Casa da Música – main auditorium architect features to consider in design.*

8. CONCLUSIONS AND FUTURE

Access to observe Orquestra Nacional do Porto rehearse the two selected compositions will be on the days preceding the presentation and in the main auditorium. This is optimal as the build can commence immediately following the initial observations so that a plan of action is established between the artist, director, and crew. The Casa da Música crew is one of the best I have worked with in the world so I am confident that we will together approach what is possible with the available equipment. An opening introduction will be given by the author in line with the background, history and issues of design that are presented herein. Anticipated are audience comments and reflections as a closure to the presentation. Providing the preliminary research is accepted by the parties concerned as an indication of what may lie ahead it is planned to begin drafting a proposal for funding the building of a team of artists with the capacity to improvise with their medium so as to collaborate together to push the boundaries of the genre. Further cross-informing is anticipated to evolve parallel work. The systemic overview involves the creation of specific compositions that innately embrace the multisensory aspects of the work – not, as in the case of the presentation, where an interpreted improvisation is offered post musical composition. In this way the concept is envisioned as potentially adding to the body of work of those composers who have composed in this way before – Alexander Nikolayevich Scriabin, the noted Russian composer, who was born in 1871, comes to mind. Rather than a single composer the proposed team design will involves interchangeable invited artists with inter/multidisciplinary competences. This is so collaborative compositions will specifically target inter/multisensory stimulus, the environment, and the situation of presentation from the outset – such a combination could be great or doomed to failure. Archives are proposed to be packaged and emitted via a space craft to enlighten whoever may be out there…watching… listening… and feeling, as it is posit that even in space one can aesthetically resonate!

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[2] http://www.youtube.com/watch?v=65gAT_RAfvU

[3] http://www.imaja.com/blisspaint/index.html

[4] http://www.aotea.org.nz/

[5] http://www.youtube.com/watch?v=DfyosGOuED8;

[6] http://www.youtube.com/user/touchcompass; http://www.touchcompass.org.nz

[7] http://www.youtube.com/watch?v=w2gVC-pnyFo;

[8] http://www.caitlinsmith.com/

[9] http://www.martin.com/casestory/casestory.asp?id=572

[10] http://www.youtube.com/watch?v=gTjvCh-XB2o

[11] http://www.youtube.com/watch?v=iDX8K6Vq4kk

[12] http://www.youtube.com/watch?v=RmiWYTytf_0

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[19] http://www.bris.ac.uk/carehere – bodypaint programme, Trocca & Volpe (DIST University Genoa, Italy) when at CAREHERE Lund meeting: conceptualised and initiated by Brooks.

APPENDIX

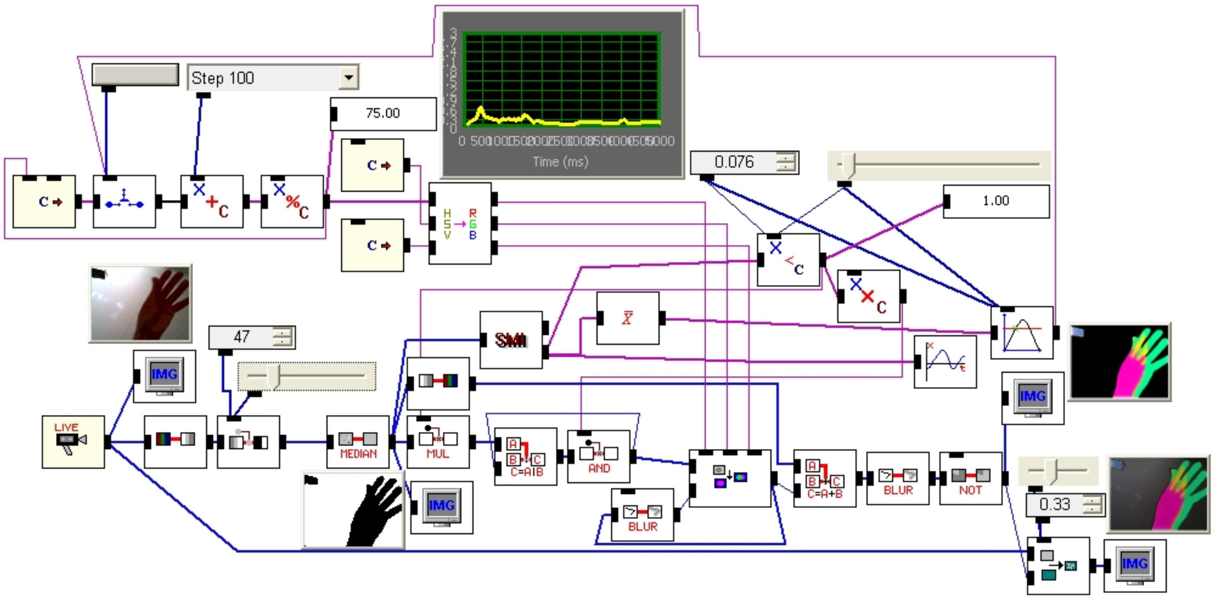

Figure 6. *Eyesweb Bodypaint patch. Eyesweb 'bodypaint' algorithm created in Lund, Sweden as an outcome of the CARE HERE European Project IST-20001-32729 (Creating Aesthetic Resonant Environments for Handicapped, Elderly and Rehabilitation). This will be a used tool in the presented work with the addition of data streams that will map motion to MIDI control of lighting. A full list of the patch parameters is available from the author. Image windows represent from left to right – source – background subtracted – bodypaint output – video mixer output. Real-time control can be assigned to MIDI control input to operate sliders to determine contrast and mixer blend. 'Step' box determines colour differential chart. If you utilise this patch please acknowledge accordingly.*[19]

Label	Type	Comment
LinearFilterBlur_1	Imaging.Filters.LinearFilterBlur	Blurs the input image.
CopyColouredMask_1	LundCareHere.CopyColouredMask	Copies the bw image passed, colouring it according to the implicit mask in the image.
Generator_1	Math.Scalar.Input.Generator	Generates various type of signal.
Generator_1	Math.Scalar.Input.Generator	Generates various type of signal.
Display_1	Math.Scalar.Output.Display	Display the input scalar value.
HSVToRGB_2	Imaging.Conversion.HSVToRGB	This block converts a value from HSV to RGB.
ColorToGray_1	Imaging.Conversion.ColorToGray	Converts a color image to gray scale.
Threshold_3	Imaging.Operations.Threshold	Thresholds the source image.
NonlinearFilter_1	Imaging.Filters.NonlinearFilter	Performs a nonlinear filtering on the input image.
GrayToColor_1	Imaging.Conversion.GrayToColor	Convert a grayscale image to a rgb image.
DyadicArithmeticOp_1	Imaging.Operations.DyadicArithmeticOp	Performs a dyadic arithmetic operation on the two input images.
LinearFilterBlur_1	Imaging.Filters.LinearFilterBlur	Blurs the input image.
ConstOp_1	Math.Scalar.ConstOp	Execute the selected operation with a constant.
Trigger_1	Generic.Trigger	Propagates the input to an output, whenever a pulse command is received.
Generator_1	Math.Scalar.Input.Generator	Generates various type of signal.
ConstOp_1	Math.Scalar.ConstOp	Execute the selected operation with a constant.
Display_1_camera	Imaging.Output.Display	Display a IPL image in a popup window. Camera input.
Display_1_background_subtract	Imaging.Output.Display	Display a IPL image in a popup window. Background subtract image.
ThreshCrossing_1	Math.Scalar.ThreshCrossing	Output the input value every time it crosses (upward, downward or both) a threshold value.
XvsTime_1	Math.Scalar.Output.Graph.XvsTime	Plots the input scalar value versus time, using a 2-D carthesian graph.
RunningOperation_1	Math.Scalar.RunningOperation	Calculates running operations on the last N samples.
SMI_2	LundCareHere.SMI	This block calculates the Silhouette Motion Images and the quantity of motion on the input image.
MonadicArithmeticOp_1	Imaging.Operations.MonadicArithmeticOp	Performs a monadic arithmetic operation on a single input image.
ScalarUnaryOpLogical_1	Math.Scalar.ScalarUnaryOpLogical	Perform a logical operation on the input scalar value against the parameter 'Value'.
Display_1	Math.Scalar.Output.Display	Display the input scalar value
Display_1_bodypaint	Imaging.Output.Display	Display a IPL image in a popup window. Bodypaint output.
MonadicLogicalOp_1	Imaging.Operations.MonadicLogicalOp	Performs a monadic logical operation on a single input image.
DyadicLogicalOp_1	Imaging.Operations.DyadicLogicalOp	Performs a dyadic logical operation on the two input images.
MonadicLogicalOp_2	Imaging.Operations.MonadicLogicalOp	Performs a monadic logical operation on a single input image.
ConstOp_1	Math.Scalar.ConstOp	Execute the selected operation with a constant.
FrameGrabber_1	Imaging.Input.FrameGrabber	Grabs image continuously from a frame grabber device.
VideoMixer_1	LundCareHere.VideoMixer	A video Mixer
Display_1_mixer	Imaging.Output.Display	Display a IPL image in a popup window. Mixer output.

Figure 7. *Eyesweb Bodypaint patch list for cross-reference to image in Figure 6.*

ICDVRAT 2008

Session I

Cognitive Rehabilitation

Chair: Belinda Lange

Effect of playing computer games on decision making in people with intellectual disabilities

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ABSTRACT

People with intellectual disabilities have difficulty making decisions and this may hinder their independence and inclusion in society. Interactive computer software may give them the opportunity to practice the underlying components of this skill. A previous study indicated that playing a computer game improved choice reaction time. This study aimed to discover if repeated sessions playing a computer game involving aspects of decision making, such as collecting relevant information and controlling impulsivity, would improve performance in two non-computer based tests of decision making. 12 adults with intellectual disabilities were randomly assigned to either an intervention group or control group. They were all exposed to 10 twice weekly sessions, playing either the intervention game or the control game, which involved simple reaction time only. All participants completed two non-computer based tests of decision making at baseline and post-intervention. After repeated sessions, the intervention group showed a significant improvement in game score, with researcher assistance significantly decreasing. At follow up, the intervention group showed a significant decrease from baseline in the number of guesses made before guessing correctly on both of the decision making tests. The decrease observed in the control group failed to reach significance.

1. INTRODUCTION

People with intellectual disabilities are one of the most vulnerable and socially excluded groups, facing daily issues of oppression and discrimination (Thomas and Woods 2003). The majority of this group of people do not have jobs, live in their own homes or have any choice over important issues such as who cares for them or even day to day issues such as the food they eat. Due to this denial of choice and decision making, they often feel they have no control over their lives. The terms "choice" and "decision" making are used closely and interchangeably, however choice is described as "making an unforced selection of a preferred alternative from two or more options" (Stancliffe, 2001, page 92). This differs from decision making, which is acknowledged by Jenkinson and Nelms (1994) to involve more than just a simple expression of preference. They describe the process as "understanding an issue, identification and informed evaluation of options, communication of a decision and commitment to an action". Research indicates that people with intellectual disabilities have difficulty making choices and decisions (Jenkinson and Nelms, 1994). This study suggested that people with intellectual disabilities frequently fail to use a systematic decision-making process that requires them to search for all the relevant information and evaluate alternatives before making a decision. Instead they often simply draw upon a narrow range of solutions from past experiences and apply them to new situations.

There is some evidence that this is exacerbated by a constant denial of choice (Jenkinson and Nelms, 1994; Cooper and Browder, 2001) due to poor resources, assumptions of incompetence and carers having time constraints or concerns about risks. Several studies (Parsons et al, 1998; Kennedy and Haring, 1993; Kern et al, 1998) have found that increasing choice opportunities has improved participation, engagement and behaviour during activities. Studies trying to encourage staff to offer more opportunities for choice and decision making have also been effective (Belfoire et al, 1994; Cooper and Browder, 2001). Could these opportunities be expanded through computer based practice of the component skills of decision making?

Recent research on the beneficial effects of playing action video games suggests that the skills practiced in these games transfer to other situations. Green and Bavelier (2003) found that playing action video games can give a person the ability to monitor more objects in their visual field and do so faster than a person who does not play such games. In their most recent study, Green and Bavelier (2007) found a causative relationship between action video game playing and increased spatial resolution of visual processing. In order to explore whether similar transfers might take place in people with intellectual disabilities, Standen et al (2006) assessed the effect of playing a switch controlled computer game with a time limit for responses on choice reaction time. They found a significant decrease in choice reaction time in the intervention group compared to the control group who, for the same amount of time, played a game with no time limit.

Choice reaction time is only one aspect of decision making and measuring decision making in people with intellectual disabilities is not straightforward. There are standardised tests for this purpose but they pose problems. The Cambridge Gambling Task (Rogers et al, 1999) which measures quality, speed and risk-adjustments of decisions, is designed for the non-disabled population and is too complex for people with intellectual disabilities. The Information Sampling Task (IST) (www.cantab.com) measures the amount of information collected before a decision is made and impulsivity ie making a decision too early. It is simpler than the Gambling Task and does not rely on language. However, as it is computer based an improved outcome in people with intellectual disabilities could be just due to increased familiarity with computers.

The current study aims to assess the effect on decision making of playing a computer game which involves making a decision based on visual information.

2. METHODS

2.1 Design of Study

Baseline measures of decision making were compared with post intervention measures in an intervention group and a matched control group.

2.2 Participants

12 adults with intellectual disabilities were recruited from a local day centre. Potential participants were nominated by specialist carers at the centre if they matched the following inclusion criteria:

- adequate visual ability to be able to view the screen.
- adequate motor ability to operate keys without assistance.

Participants were grouped into pairs matched on age and ability as measured by the British Picture Vocabulary Test (BPVS, Dunn et al, 1997) and the members of each pair were randomly allocated to either the intervention or control group. Their characteristics are displayed in Table 1.

Table 1. *Characteristics of Participants.*

	Intervention Group N=6	**Control Group N=6**	**All Participants N=12**
Median Age in Years	33.5	42.0	41.25
Median Raw Score (BPVS)	57.0 (SD = 35.5)	59.3 (SD = 38.7)	58
Male:Female Ratio	3:3	5:1	8:4
Ethnicity	6 Caucasian	6Caucasian	12 Caucasian

2.3 Interventions

Intervention Task. Cheese Factory, based on Tetris, is a game written in Flash specifically for people with severe intellectual disabilities. It involves sections of various sizes (eg quarters) from whole rounds of cheese falling from the top of the screen. Cheese sections could be left to form a pile immediately below or using the arrow keys on the keyboard sent to fall either left or right. When a cheese section appears at the top of the screen, the player must decide which direction to move it so that the section falls on to the pile where there is an appropriate gap for it to form a whole cheese. The game has a number of levels based on the varying speed of appearance of the stimuli or shape of the stimuli and thus levels were available to accommodate more disabled players. The level participants played at and the scores they achieved in each session were recorded.

Control Task. Running Man was also written in Flash and designed specifically for people with intellectual disabilities and success is dependent on speed of simple reaction time.. It involves a man jogging across the screen and encountering obstacles (e.g a rock) on his way to the finishing line. The player has to make the man jump over the obstacles by a single click of the space bar on the keyboard. If they fail to do this at the right time, the man crashes into the obstacle. The game could be made more challenging by increasing the speed that the man ran and increasing the number of obstacles. The level participants played at and the number of crashes in each session were recorded.

2.4 Measures

Picture Guess Test. This test was designed on similar principles to the standardised Information Sampling Test (IST) from CANTAB. The participant has to guess which of four pictures displayed in front of them is depicted on one placed face down in front of them. This is cut into 12 pieces like a jigsaw and in order to make a decision they can turn over as many pieces as possible before they make a guess. Outcome measures are the number of pieces turned over, number of guesses before a correct guess is made and time taken to guess correctly averaged over the four times the test was repeated.

Picture Completion Test. This test was a simplified version of Raven's Matrices. The participant has to identify the missing segment from a display of six in order to complete a larger pattern presented in a 3×3 grid. The larger pattern has two dimensions, such as a change in number horizontally and a change in colour vertically. The number of guesses they could make was limited to four, as there were only six possible segments to choose from, therefore once the participant has made four incorrect guesses, that test item was terminated. The test comprised two introductory items and then three sections, each focused on different dimensions that increased the difficulty of the tasks (eg colour and number; shape and number; shape and orientation), with three items in each section making 11 sheets in total. Outcome measures were the number of guesses made; time taken to make a correct guess and how many items they could complete.

In both tests participants could make their guesses verbally or by pointing.

Performance on Intervention and Control Tasks. For both tasks level of difficulty at which participants were playing was recorded as well as scores obtained for the intervention group and crashes for the control group. To ensure any change in performance was not due to an increase in supervisor assistance all the sessions with both groups were videotaped and analysed for amount of supervisor assistance given using a method established in an earlier study (Standen et al, 2002).

2.5 Procedure

After completing the BPVS, all participants were assessed at baseline on the two measures of decision making before being assigned to either the intervention or control group. Each participant was scheduled for 10, twice weekly sessions of 20 minutes over five weeks. The sessions were timed using a stopwatch and when 20 minutes had passed the session was terminated to ensure everyone had equal lengths of exposure to the games. One of the researchers (FR) sat alongside them to give assistance and encouragement. Five sessions were recorded on videotape, with the camera positioned to view both the participant and the researcher sitting next to them. After the tenth session all participants repeated the two outcome measures of decision making.

2.6 Analysis

To minimise bias the tapes were scrambled so that the researcher (FR) was unaware of whether the session being analysed was earlier or later in the study. Repeat reliability was established on four randomly selected sessions. Video collected data were expressed as a percentage of session duration. Scores and crashes were adjusted for length of session. Statistical comparisons were made using t tests for data that met the requirements for parametric analysis and the Wilcoxon Signed Ranks Test for paired data that did not meet these requirements.

3. RESULTS

3.1 Did both groups improve their performance on the intervention tasks?

For the Intervention Group there was a significant increase in scores achieved between the first and the tenth sessions ($t = 3.01$, $df = 5$, $p<0.03$) in spite of a steady increase in the level of difficulty at which they were playing the game (see Figure 1.) This was not due to the amount of help they received from the researcher as this decreased over repeated sessions with a significant ($t = 22.02$, $df = 5$, $p< 0.0001$) decrease in the percentage of time in which help was given between sessions one and ten (see Figure 2).

Similar results were found for the control group (see Figure 3). The fall in the number of crashes from session one to session ten did not reach significance ($Z = 1.16$, $P<0.25$) but there was a significant reduction in the percentage of session time in which help was received from sessions one to ten ($t = 13.76$, $df = 5$, $p< 0.001$) (see Figure 4).

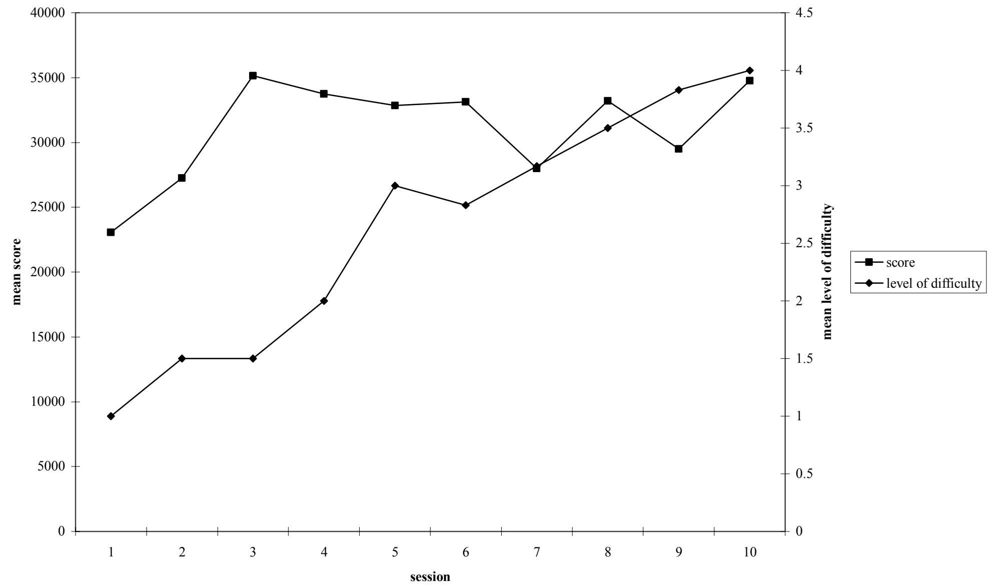

Figure 1. *Means score and level of difficulty in each session for the intervention group.*

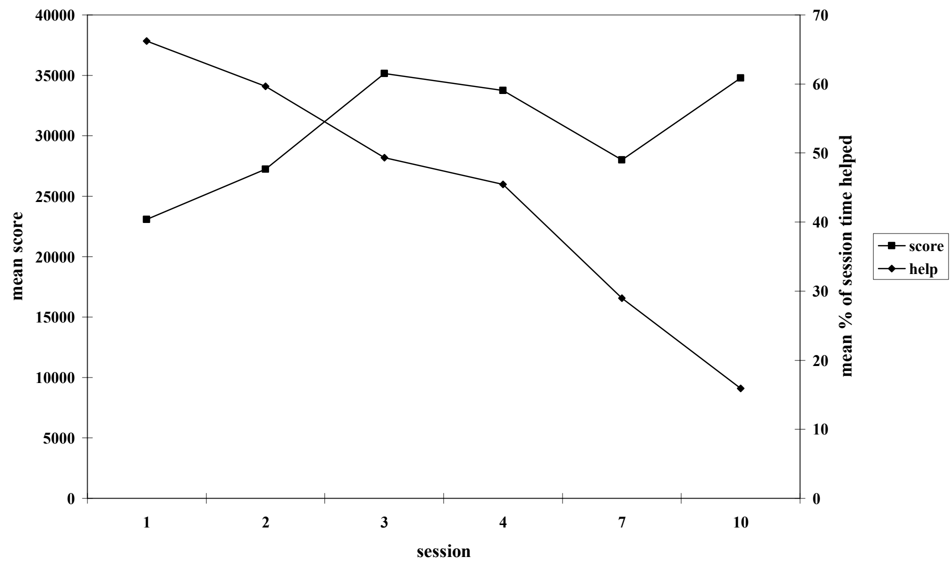

Figure 2. *Mean percentage of time helped and score in each session for the intervention group.*

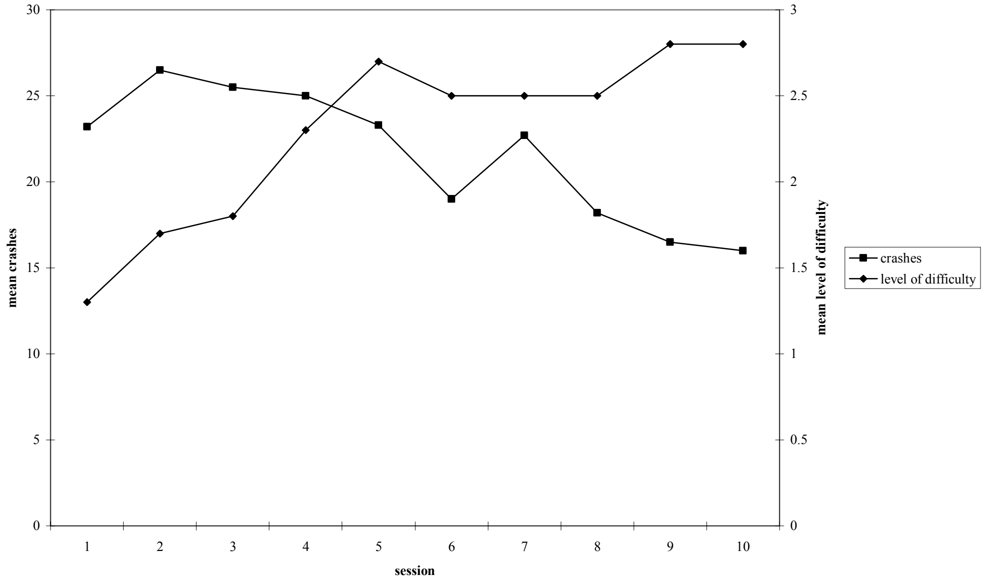

Figure 3. *Mean number of crashes and level of difficulty in each session for the control group.*

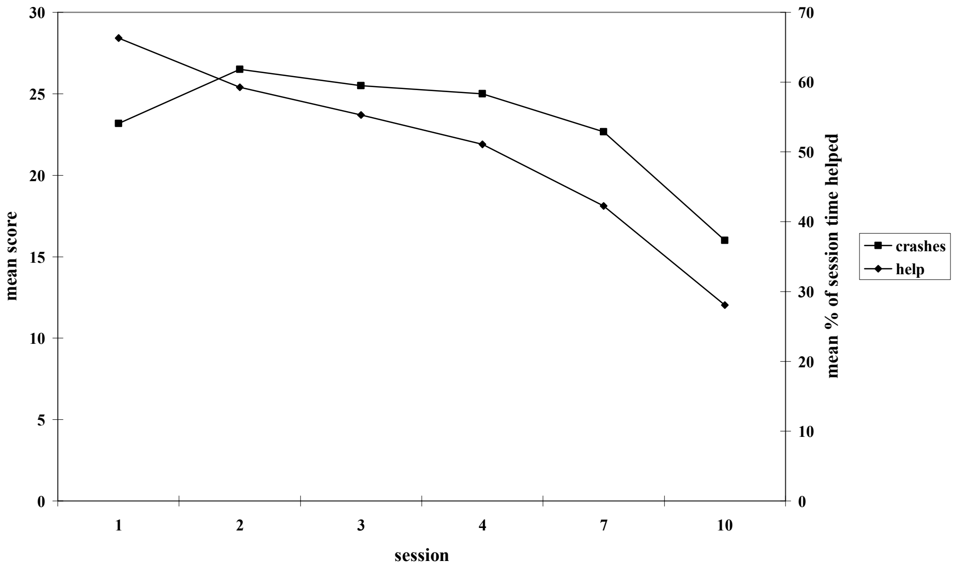

Figure 4. *Mean percentage of time helped and number of crashes by session for the Control group.*

3.2 Is there a difference between the Intervention and Control Groups in change from baseline to post-intervention on the two tests of decision making?

For the Picture Guess Test both groups showed a reduction in the number of guesses before the correct guess from baseline to post intervention (see Table 2). However this reduction was only significant for the Intervention Group ($Z = 2.21$, $p < 0.03$). For the Intervention Group this was accompanied by an increase in the number of pieces turned over before a correct guess was made although this did not reach significance. None of the other changes in scores for either group were significant.

For the Picture Completion Test both Groups showed a reduction in the number of guesses before the correct guess from baseline to post intervention (see Table 3). However this reduction was only significant for the Intervention Group ($t = 6.74$, $df = 4$, $p<0.003$). Although for both groups there was an increase in the number of sheets completed from baseline to post intervention, neither reached significance. None of the other changes in scores for either group were significant.

Table 2. *Picture Guess Test variables at baseline and post intervention.*

	Intervention Group(n=6)		Control Group (n=6)	
	Baseline	**Post Intervention**	**Baseline**	**Post Intervention**
Median number of guesses (range)	1.63 (1.25 - 2.25)	1.00 (1.0 - 1.25)	1.75 (1.5 – 4.0)	1.63 (1.0 – 3.0)
Median number of pieces turned over (range)	3.50 (1.75 - 3.75)	3.75 (2.75 - 5.75)	4.13 (2.0 - 8.5)	4.00 (1.25 - 6.25)
Median time to guess correctly (range)	25.00 (11.25 - 46.75)	23.38 (12.75 - 59.75)	32.88 (11.25 - 106.5)	27.63 (7.75 - 113.75)

Table 3. *Picture Completion Test variables at baseline and post intervention.*

	Intervention Group(n=6)		Control Group (n=6)	
	Baseline	**Post Intervention**	**Baseline**	**Post Intervention**
Median number of sheets completed (range)	9.00 (0 -11.00)	10.00 (2.0 - 11.0)	4.50 (0 -11.00)	6.50 (1.0 - 10.00)
Mean number of guesses (SD)	2.60 (0.65)	1.87 (0.76)	2.35 (0.67)	2.00 (0.74)
Median time to guess correctly (range)	30.80 (13.45 - 50.33)	36.27 (23.0 - 45.91)	27.73 (17.0 -115.00)	46.22 (23.56 - 97.75)

4. DISCUSSION

This study was successful in setting an appropriate level of difficulty for the intervention task as all participants showed a steady increase in performance on Cheese Factory in terms of scores obtained and level of difficulty at which they were prepared to play. This was in spite of a decreasing amount of help from the researcher who sat alongside them. For the control group their increase in performance was not significant. This may have been partly due to the performance indicator chosen. In a previous study using this game, the outcome measure chosen was the number of effective switch presses (ie those presses that resulted in a successful clearance of the obstacle) as a proportion of number of switch presses made. This indicated the degree to which participants were pressing at a high rate in the hope that by chance they would press the switch at the right time. It was hoped that this strategy would decrease as participants became more proficient at the game. A second explanation for the lack of significant improvement was that the level of difficulty of this game was too high. One participant never really seemed to grasp the principle of the game and showed no improvement over the ten sessions. This is one danger in including participants with a wide range of ability. Table 1 showed that although the two groups were matched, there was much variability in participants' BPVS scores.

However, even with the short intervention time, small sample size and non-standardised tests the intervention group showed a significant decrease in the number of guesses before guessing correctly from baseline on both tests. The control group showed no significant change. Fewer guesses implies they are being less impulsive and taking fewer risks (Rahman et al, 2001). Indeed, this explanation is supported by the fact that in the Picture Guess Test, at post-intervention, the intervention group were turning over more pieces before making a correct guess and are collecting and processing more information before making a guess. This measure decreased from baseline to post-intervention for the control group. Collecting insufficient evidence is a common feature of decision making deficits (Rahman et al, 2001; Mavaddat et al, 2000).

It is worth mentioning another of the changes that failed to reach significance. Time to guess correctly decreased for both groups in the Picture Guess Test. For the Intervention Group this occurred in spite of turning over more pieces of the picture and implies an increased ability to process information and to arrive at a conclusive decision faster. For the Picture Completion Test, it is difficult to conclude anything from this measure as both groups were completing more items at post-intervention testing. This would have involved them completing much more difficult items and for this they may have needed more time to make a selection from the display.

With such a small sample and non-standardised outcomes it is dangerous to conclude too much from the results and to be too certain about the implications of the significant results. However, the study does provide valuable information from which future studies can be designed. Although a small sample size, all twelve participants completed all sessions indicating that the procedure was enjoyable to them and presented sufficient challenge to keep them interested (Gredler 2003) but not too much to be discouraging. The tests used, while not standardised, were developed with the advice of several clinical psychologists who work in intellectual disability. The tests have face validity but now need repeat reliability and construct or criterion validity establishing. For the Picture Completion test, some easier levels should be introduced at the beginning as it was very challenging for some of the participants.

Although these challenges need to be overcome, this study supports the ever expanding body of research which shows that interactive computer software does have a role in benefiting people with intellectual disabilities (Standen and Brown 2004, 2006). In providing a safe environment in which to practice making their own decisions without fear of negative consequences (Cromby et al, 1996) it may help them to overcome barriers to decision making, giving them more confidence and opportunity to take charge of their lives.

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Performance within the virtual action planning supermarket (VAP-S): an executive function profile of three different populations suffering from deficits in the central nervous system

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ABSTRACT

Executive functions are those higher-order functions required for performing complex or non-routine tasks. People exhibiting Central Nervous System (CNS) deficits often manifest impaired executive functions, compromising return to full everyday activity and occupation. Such individuals have difficulty performing mundane daily living activities, and especially complex activities – termed Instrumental Activities of Daily Living (IADL). The use of ecologically valid, functional virtual environments constitutes a novel solution to evaluation. The Virtual Action Planning Supermarket (VAP-S) allowed us to compare performance among 3 groups of clients: post-stroke, Minimal Cognitive Impaired, and schizophrenics, and to analyze predictive group membership of the clients (N=83). Results supported study objectives, revealing distinctive performance profiles per group.

1. INTRODUCTION

Executive functions (EF) represent those higher-order functions required to perform complex or non-routine tasks (Godefroy, 2003). Deficits in EF refer to a range of impairments in the sequencing and organization of behavior, and include problems in attention, planning, problem-solving, multitasking, monitoring and behavioral control (Mateer, 1999; Burgess et al, 2000). These deficits may be the consequence of brain damage resulting from traumatic brain injury, stroke or neurodegenerative diseases (Dubois et al, 1991). EF impairments are typically manifested by marked distractibility, difficulties in initiating or suspending activities, exercising mental flexibility, as well as learning novel tasks, despite apparently intact cognitive abilities (Shallice and Burgess, 1991). Individuals with EF impairments evidence handicaps in performing daily living activities, especially those more complex activities, known as Instrumental Activities of Daily Living (IADL) (Chevignard et al, 2000; Fortin et al, 2003). IADL refers to the autonomous conduct of living functions, including preparing meals, managing money, shopping for groceries or personal items, doing light or heavy housework, and using a telephone (National Center for Health Statistics, 2008).

Many tests have been developed to assess different aspects of EF (Godefroy et al, 2004), however, some are limited because they are conducted in artificial situations, engage subjects in stressful and prolonged evaluations, and rely on the self-reporting of cognitive abilities (Odhuba et al, 2005; Chaytor et al, 2006). Problems of ecological validity and biased self-reports are additional concerns, especially among persons with cognitive deficits.

During the past decade, neuropsychological testing has shifted from traditional pencil-paper task tests to computerized assessment tests. The advent of Virtual Reality (VR) promises a range of important benefits for assessment and intervention. VR technology significantly enhances computerized assessments by generating 3D, ecologically-valid stimuli and environments, within which behavioral responses may be objectively measured. Moreover, VR has an additional edge over real-world behavioral observations via the provision of a controlled stimuli environment, where cognitive challenges are presented simultaneously with precise regulation of distractive auditory and/ or visual stimuli (Rizzo and Kim, 2005).

Until recently, the application of VR technology was severely hampered by the lack of inexpensive and user-friendly VR systems. The introduction of newer platforms employing more user-friendly software, has generated an upsurge of potential applications to medicine in general, and rehabilitation in particular. The Virtual Action Planning - Supermarket (VAP-S) (Klinger et al, 2006), was designed for assessing and training individuals to plan a pre-determined purchasing task (Marié et al, 2003). As a VR platform, the VAP-S represents an example of a valid and reliable method to assess EF disabilities in people with deficits in their Central Nervous System (CNS).

The goal of the present study is to compare the respective performance profiles of three populations suffering from CNS deficits resulting from different origins, based upon their distinctive performance on the VAP-S.

2. METHOD

2.1 Participants

Three groups of participants were sampled. The first group included 23 patients after a stroke, with a mean age of 59.1 years (SD 5.5). The second group included 27 patients diagnosed with mild cognitive impairment (MCI), with a mean age of 69.5 years (SD 7.3). A third group included 30 patients diagnosed with schizophrenia and their mean age was 46.7 years (SD 10.6).

2.2 Instrumentation

2.2.1 Task and apparatus. The VAP-S was designed to assess and train the ability to plan and perform the task of purchasing items on a shopping list (Klinger et al, 2004). In fact this original paradigm, similar to the ‘test of shopping list’ (Martin, 1972), includes a series of actions, described as a task, and allows an analysis of the strategic choices made by participants and thus their capacity to plan.

The VAP-S simulates a fully textured, medium size supermarket with multiple aisles displaying most of the items that can be found in a real supermarket. There are also four cashier check-out counters; a reception point and a shopping cart (see Figure 1). Some obstacles, like packs of bottles or cartons, may hinder the advance of the shopper along the aisles. In addition, virtual humans are included in the supermarket such as a fishmonger, a butcher, check-out cashiers and some customers.

Figure 1. *The original French version of the virtual supermarket (Klinger et al., 2004)*

The test task is to purchase seven items from a clearly marked list of products, to then proceed to the cashier’s desk, and to pay for them. Twelve correct actions (e.g., selecting the correct product) are required to completely succeed in the task. Actions are considered as incorrect if the participant: 1) chooses items that are not in the list or chooses the same item twice; 2) chooses a check-out counter without any cashier; 3) leaves the supermarket without purchasing anything or without paying; or 4) stays in the supermarket after the purchases. A training task which is similar, but not identical, to the test is also available to enable the user to get acquainted with the virtual environment and the tools. The task-related instructions are, at first, written on the screen and the target items to purchase are displayed on the right side of the screen. As the participant

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progresses with the purchases, the items appear in the cart and disappear from the screen. The cashier-related instructions are verbal and are given before the beginning of the session.

The participant enters the supermarket behind the cart, as if he is pushing it, and moves around freely by pressing the keyboard arrows. He experiences the environment from a *first person perspective* without any intermediating avatar. The participant is able to select items by pressing the left mouse button. If the item selected is one of the items on the list it will transfer to the cart. At the cashier check-out counter, the participant may place the items on the conveyor belt by pressing the left mouse button with the cursor pointing to the belt. He may also return an item placed on the conveyor belt to the cart. By clicking on the purse icon, the patient may pay and proceed to the supermarket exit.

Two main tools were used to create the VAP-S: 3D Studio Max from Autodesk (www.autodesk.com) and Virtools™ Life Platform from Dassault Systèmes (www.virtools.com). The original VAP-S was adapted by E. Klinger for use by an Israeli population; the names of the aisles and grocery items, as well as all the elements of the task were translated to Hebrew (see Figure 2).

Figure 2. *The Hebrew version of the VAP-S (adapted by Klinger, 2005).*

2.2.2 Outcome measures. The VAP-S records various outcome measures (positions, times, actions) while the participant experiences the virtual environment and executes the task. At least eight variables can be calculated from the recorded data: the total distance in meters traversed by the patient (referred to as the trajectory), the total task time in seconds, the number of items purchased, the number of correct actions, the number of incorrect actions, the number of pauses, the combined duration of pauses in seconds, and the time to pay (i.e., the time between when the cost is displayed on the screen and when the participant clicks on the purse icon).

2.3 Procedure and data analysis

Following a training session dedicated to familiarization with the software and supermarket, participants completed the task without any time limitations. Each subject was assessed in a 20 to 40-minutes individual session either at the hospital, rehabilitation clinic or at home. Data were analyzed by comparing the 3 study groups using a MANCOVA procedure, with the covariate of age due to significant differences between the groups. Further contrasts were conducted to pinpoint specific differences between each of the groups. In addition, a discriminant analysis was performed to examine which of the outcome measures of the VAP-S significantly predicted group membership of the participants.

3. RESULTS

Initial analysis of the data showed that 14 participants with Schizophrenia (47%) were unable to complete the task and omitted the final step (paying at the cashier), therefore in order to perform MANCOVA and discriminant analysis with all participants in that group we omitted the outcome measure "time to pay". Performance results within the VAP-S of the three study groups are presented in table 1. Significant between group differences were obtained for performance in the virtual supermarket based on the MANCOVA test ($F(14,140)= 5.15$, $p= .0001$, ES-$\eta2= .34$), however no effect for age was found ($F(7,70)= 0.42$, $p= .89$, ES-$\eta2= .04$). Performance differences were significant for all outcome measures and the contrasts showed significant differences to be evident between all groups. Comparing to the two other groups the MCI group participants were slower performers, making more stops and wrong moves, yet purchasing more items. The stroke group participants, compared to the Schizophrenia group, were slower performers, making more stops and wrong moves, yet purchasing more items. The Schizophrenia group performance had a larger variance than the other two groups in most outcome measures (See Table 1). The discriminant analysis showed that the outcome measures of the VAP-S composed a significant function (Wilks' Lambda= .29; $p<.0001$) and predicted group membership of 71.3% of the participants (kappa=.57; $p<.0001$). Table 2 shows the predicted groups membership of each group; indicating that the prediction was more accurate with the MCI and Stroke groups.

Table 1: *Performance of the three study groups within the VAP-S along with the results of contrasts of the MANCOVA.*

	Stroke (N=23)		Mild Cognitive Impairment (N=27)		Schizophrenia (N=30)		
	Mean	SD	Mean	SD	Mean	SD	Contrasts*
Trajectory	200.71	83.08	309.89	91.74	156.78	106.68	St<MCI MCI>Sch
Total time of performance (min)	10.44	4.05	17.86	3.95	7.21	5.11	St<MCI>Sch St>Sch
Number of items purchased	5.91	1.53	6.93	.27	3.43	2.96	St<MCI>Sch St>Sch
Number of correct actions	10.52	2.59	10.93	2.72	6.73	4.74	St>Sch MCI>Sch
Number of incorrect actions	2.78	3.01	7.52	2.58	1.50	3.05	St>Sch MCI>Sch
Number of pauses	23.91	10.80	38.93	8.77	13.23	8.03	St<MCI>Sch St>Sch
Total duration of pauses (sec)	5.39	3.05	9.58	3.38	3.56	2.58	St<MCI MCI>Sch

* Shows significant differences between the various groups
St=stroke; MCI=Mild Cognitive Impairment; Sch=Schizophrenia

Table 2: *Predicted group membership according to the discriminant analysis*

Original groups	Predicted groups			Total
	Stroke	MCI	Schizophrenia	
Stroke	17	3	3	23
MCI	4	23	0	27
Schizophrenia	12	1	17	30

4. DISCUSSION

Results of this study supported our stated objective. A distinctive performance profile for each group was demonstrated: while the patients with Schizophrenia performed, in general, similarly to the post-stroke patients, significant differences were found between these two groups on five outcome measures (See Table 1). Analysis of MCI patients' performance showed that although their strategies appeared to be less efficient (e.g. made more stops and incorrect actions), they were, nevertheless, able to complete the task (i.e. purchase more items). People who are diagnosed with MCI are thought to be in a critical transition between normal aging and dementia. The definition of MCI thus needs to be expanded to include clinical heterogeneity, with two recognized subtypes: amnesic - including memory impairment, and non-amnesic - including impairment in other non-memory cognitive domains. Primary non-amnesic deficits incorporate limitations in executive functioning (EF) (Winblad et al, 2004). The complex picture of overall task success, albeit with less efficient strategies, may reflect this transition. These results emphasize the advantage of the VAP-S outcome measures which provide information about the process of performing a task and not only the end result. Performance of the patients with Schizophrenia suggests that they have deficits in executive functions, which was reported in the literature (Katz et al, 2007). They performed the task rapidly and made fewer pauses, however they committed more errors, failed to purchase their needed items and did not approach the cashier to pay - the final step of the task. Finally, it seems that when looking at all the outcome measures, the patients with stroke performed the task better then the other groups.

The results of the discriminant analysis showed that the VAP-S measures provide an effective way to differentiate among the three respective groups: more than 70% of the participants were correctly categorized according to their group and initial diagnosis. The categorization was more accurate in the MCI and stroke groups than in the Schizophrenia group which also showed a larger variance in their performance. This promising finding may enable clinicians to utilize a brief test and user-friendly environment in order to provide a valid report about patients' EF and their respective diagnoses.

5. CONCLUSION

In the future, this environment could enable evaluation and prediction of patient performance, in relation to other components of executive functioning, such as inhibition and sequence. The relatively low cost of this virtual environment makes it an attractive and feasible option for wider utilization and implementation in rehabilitation clinics. Future studies will aim to develop a more comprehensive outcome measure to the task as well as use this environment as a training tool with various populations. Furthermore, the VAP-S will be examined in a direct comparison with a real supermarket shopping task, with the objective of revealing the relationship between a virtual environment and real life activities.

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Virtual reality and neuropsychology: a cognitive rehabilitation approach for people with psychiatric disabilities

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ABSTRACT

This pilot-study evaluated the feasibility of a 9 month Cognitive Rehabilitation Program – using Virtual Reality and the Integrated Psychological Therapy (IPT) – to improve cognitive functioning in people with schizophrenia. In order to assess the program it was applied (pre and post) the WCST, WAIS-III sub-tests, Stroop Test, and The Subjective Scale to Investigate Cognition in Schizophrenia. Results identified significant differences ($p<0.05$) between pre and post tests in the subjective and objective assessed cognitive dimensions. The results point out that virtual reality technology and IPT may be a significant resource and intervention methodology in the cognitive remediation of people with psychiatric disabilities.

1. INTRODUCTION

Schizophrenia is a stress-related, neurobiological disorder characterized by disturbances in the form and content of an individual's thought and perceptual processes, affect, social, and instrumental role behaviour. The pervasive impact of schizophrenia across perceptual, cognitive, emotional and behavioural domains, as well as the heterogeneity within those domains requires a multimodal and comprehensive approach to treatment and rehabilitation which involves the individual and his or her environment.

However, cognitive impairment it has come to be seen (since the 1980s) as a core feature of the disorder and an important determinant of course of illness, reliably present in the majority of patients, independent of positive symptoms such as delusions and hallucinations, a major cause of poor social and vocational outcome, and may interfere with the individual capacity for benefiting from psychosocial rehabilitation, especially when such intervention involves learning new skills (Goldberg et al., 1990; Green et al., 1996; Romero, 2003). Schizophrenia affects transversally all the neurocognitive functioning domains, in particular the functions related to the 'hipofrontality', such as executive functions, processing speed, memory (with special incidence in work memory), and attention (Brazo et al., 2005).

Other studies have already demonstrated that persons with schizophrenia present difficulties in terms of emotional recognition and social perception. Social perception is even being pointed out as a mediator between basic cognitive activity and social function (Kohler et al., 2000; Penn et al., 1997; Vauth et al., 2004). On other hand, there are studies indicating a strong link between neurocognitive factors, daily life activities, social problem resolution, social competencies development, and psychosocial functioning (Green et al., 1996, 2000).

The perceived impact of cognitive impairment on day-to-day functioning has led to the development of cognitive rehabilitation approaches intended to remedy these impairments, and thus improve the functioning of people with psychiatric disabilities.

In this context, professionals from different fields of action have been studying and developing cognitive rehabilitation strategies, generating controversy, and a variety of views regarding the effectiveness of each one. In general, these approaches may be classified as restorative or compensatory, as well as computerised and non-computerised. In order to distinguish and illustrate these different classifications, we will essentially refer to the approaches identified on the "Training Grid Outlining Best Practices for Recovery and Improved

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Outcomes for People With Serious Mental Illness", developed by the American Psychological Association Committee for the Advancement of Professional Practice in 2005.

The restorative approaches aim to improve cognitive functioning through a set of specified training interventions. It may be more accurate to describe these programs as "cognition enhancing" efforts (Velligan et al., 2006). Some examples of de cognition enhancing approaches are the "Attention Process Training" developed by Sohlberg and Mateer (1987), the "Neurocognitive Enhancement Therapy" program of Bell and colleagues (2001), and the "Computer-Assisted Cognitive Remediation Program" (CARC) created by Bellack and collaborators in 2005. The compensatory approaches aim to bypass or "compensate" for cognitive deficits to promote skill acquisition or functional outcome. Impairments in cognition are circumvented either by recruiting relatively intact cognitive processes or by utilizing environmental supports and adaptations to cue and sequence target behaviours (Velligan et al., 2006). The "Errorless learning" (Kern et al, 2002, 2003) and the "Cognitive Adaptation Training" (Velligan et al., 2000, 2002) are some examples of compensatory programs.

In terms of the other classification, the computerised methods usually base their intervention strategy in the "Retrainning Model", which has as its assumption individualized and specific training for each of the cognitive functions deficit through repeated instructions and exercises, with or without guided practice. Despite other, we would like to highlight the cognitive rehabilitation programs developed by Belluci and collaborators in 2003, designated "Captain's Log Software", and the "Computer-Assisted Cognitive Remediation Program" (Bellack et al, 2005). In what concerns not computerised methods it is possible to identify in the specialist literature (Belluci et al., 2003; Brazo et al., 2005; Krabbendam & Aleman, 2003; Velligan et al., 2006) references to approaches involving paper and pencil exercises/activities developed in group context, psychoeducative programs, as well as broader group intervention programs targeted not only for the development of cognitive skills but also for the social functioning, such as the "Integrated Psychological Therapy" (IPT) developed by Brenner and colleagues (1994), the "Attention Shaping" (Silverstein et al., 2005), The "Frontal / Executive Program" developed by Delahunty and Morice (1993), and the "Cognitive Remediation Therapy" developed by Wykes and colleagues (1999, 2005).

However there are also some approaches allying both computerised and non-computarised methods, which seem to present interesting results. The "Cognitive Enhancement Therapy" designed by Hogarty and Flesher in 1999, and the "Neuropsychological Educational Approach to Rehabilitation" developed by Medalia and collaborators (2005) are some examples that combine computer-based cognitive exercises with small groups training.

The heated debate and controversy surrounding the impact of all these cognitive rehabilitation methods on cognitive skills learning and generalization does not spread to the importance attributed by most experts to the influence of neurocognitive factors in the day to day activities performance (Green et al., 1996, 2000; Kohler et al., 2000; Lysaker et al., 2005; Penn et al., 1997; Vauth et al., 2004).

Recently Virtual Reality based software is thought to be potentially more representative of every-day life situations than paper-and-pencil treatment procedures or traditional computerized approaches (Pugnetti et al., 1998). Virtual Reality provides opportunities to enlarge the actual limits of cognitive rehabilitation applications providing valuable scenarios with common elements for the patients, putting them in contact to daily life activities. Immersive virtual environments appear to be the best solution to make lab situations become closer to the natural setting in the subject's perception. Vincelli and colleagues (2001) have considered Virtual Reality as the most advanced evolution of the relationship between man and computers, different from other technologies because it offers to users the chance to experience psychological states of *immersion* and *involvement* (Rizzo, Wiederhold, & Buckwalter, 1998) due to the combination of hardware and software tools with particular interactive interfaces.

Virtual Reality is a technology used in many applications, from arts to health care, in many areas, such as phobias, eating disorders, sexual disorders, and depression psychotherapy, cognitive rehabilitation and psychical rehabilitation (Costa & Carvalho, 2004; Glantz et al., 2003; Schultheis & Rizzo, 2001). In particular, in the rehabilitation field, the possibility to use virtual reality technologies has been studied and the potential based applications has been recognized (Broeren et al., 2002; Campbell, 2002; Cunningham & Krishack, 1999; Grealy & Heffernan, 2000; Pugnetti et al., 1998; Rizzo & Buckwalter, 1997; Schultheis & Rizzo, 2001).

Our view is consistent with other authors (Castelnuovo et al., 2003; Rizzo et al., 1998), who believe that the added value of Virtual reality in cognitive rehabilitation, compared to the traditional approaches, are the *customization on user's needs* (each virtual environment can be produced in a specific way focusing on the patient's characteristics and demands); the *possibility to graduate* (each virtual environment can be modified and enriched with more and more difficult and motivating stimuli and tasks); the *high level of control* (it allows professionals to monitor the level of affordability and complexity of the tasks that can be provided to patients); the *ecological validity* (a virtual environment allows to stimulate in the subjects emotional and cognitive experiences like in the real life); and the *costs reduction* (rehabilitation with Virtual Reality can be cheaper than the traditional one, mostly when it comes to the reconstruction of complex scenarios).

Due to the great flexibility of situations and tasks provided during the virtual sessions, considering time, difficulty, interest, and emotional engagement, this new technology allows, besides the diagnostic applications (Zhang et al., 2001), to enhance the restorative and compensatory approaches in the rehabilitation process of cognitive functions inside the traditional clinical protocol.

The reduced number of studies developed in this field, associated to the need of stimulating both basic cognitive functions (like executive functions, processing speed, work memory, and attention), and social-cognitive competencies (like social perception, verbal communication, social competencies and inter-personal problem resolution), was determinant to our program philosophy. This articulates virtual reality (directed to basic cognitive competencies development) with groups sessions (orientated to the social-cognitive competencies development), based on the "Integrated Psychological Therapy" (Brenner et al., 1994).

In this sense, the purpose of this study was to verify the feasibility of a Cognitive Rehabilitation Program – using Virtual Reality and Integrated Psychological Therapy (IPT) (Brenner, 1994) - to improve cognitive functioning in people with schizophrenia.

2. METHODS

2.1 Participants

14 persons with schizophrenia diagnostic (based on the DSM-IV-TR criteria - American Psychiatric Association, 2000) addressed by the "Familiars, Users, and Friends of the Magalhães Lemos Hospital" (Porto, Portugal) participated in this study. Generically the sample was predominantly male (66,7 %), with ages between 23 and 44 (x=32,0;s=6,69), single (80%), unemployed (100%), and with low qualification level (60% had the 9^{th} schooling grade or lower – compulsory schooling level in Portugal).

2.2 Instruments and procedures

The cognitive rehabilitation program we developed was implemented in the "Competencies Development Centre" in Matosinhos, Portugal, and it ran over 9 months long. The program integrated a group intervention orientated for the social-cognitive competencies development, based on the Integrated Psychological Therapy (Brenner et al., 1994), and an individual intervention directed for the cognitive rehabilitation. This resorted to the use of Virtual Reality for intervening in the most affected cognitive functions in schizophrenia – memory, attention, processing speed, and executive functions (Brazo et al., 2005; Carter et al, 1998; Cornblatt & Keilp, 1994; Landro, 1994; Poole et al., 1999; Spindler et al., 1997; Weickert et al., 2000; Weinberger et al., 1994; Wykes & Van der Gaag, 2001).

IPT is based on a building-block model which assumes that basic neurocognitive functions are necessary prerequisites for higher-order complex social functions. Training was conducted in small groups of 7 patients in 60 minute sessions 2 times per week, and proceed through 5 subprograms, arranged in a hierarchical order according to complexity of function. The first 3 subprograms represented the cognitive training component, including abstraction, conceptual organization, basic perception and communication skills training. These IPT function domains are designated Cognitive Differentiation, Social Perception, and Verbal Communication. The fourth and fifth components represent the behavioural level of social interaction and are similar to skills training approaches used elsewhere. These are named Social Skills and Interpersonal Problem Solving. Training is highly structured and manual-driven. Some studies have already demonstrated the efficacy and the cognitive and psychosocial benefits of the Integrated Psychological Therapy (Spaulding et al., 1999; Penadés et al., 2003).

The cognitive rehabilitation intervention recurring to the Virtual Reality was implemented in 20 individual sessions, occurring weekly. Each session had the duration of 50 minutes and was guided by a predefined and tested task protocol. From the available virtual reality environments, we opt to use the "Integrated Virtual Environment for Cognitive Rehabilitation -AVIRC" developed by the Rio de Janeiro Federal University, Brasil, (Costa & Carvalho, 2004), and an adaptation of the "Virtual Environments for Panic Disorder – VEPD" from the Auxiologic Italian Institute (Vincelli et al., 2000), consisting in a hypermarket, a Metropolitan and a Square. The use of these four different virtual environments with different interactivities levels and very similar to the real participants living contexts, promoted a huge diversity functional activities in laboratorial context. This was crucial for enhancing the learning generalization and transferring level.

Generically AVIRC integrated a city with streets, cars, furnished houses, a church, shops and a supermarket, which may be visited by participants and where they are asked to make some specific tasks. These require the use of cognitive functions, such as turning off the light when leaving home, turn on the radio, getting in the yellow car. In the VEPD square, among others, there is a coffee house with terrace and different persons seating and walking. The metropolitan context permits the participant to make a journey within the tube, experiencing different lines, and different stations. The supermarket virtual environment reproduces a commercial space with several products available in different shelves, workers helping, clients asking for help, and payment points.

In order to access to virtual environments it was used a computer, a monitor with high level of resolution capacity, Amplified Speakers, and an immersive virtual reality environment equipment, specifically the "I-Glasses 3D-PRO" and a "Virtual Reality Head-Tracker". The "I-Glasses 3D-PRO" permitted to the user obtaining three-dimensional visual information, which makes it appear very close to the reality scenarios. The "Virtual Reality Head-Tracker" permitted that the image gained movement conducted by the user's head movements, promoting in this way the interactivity. These equipments associated to a light and sound isolated room created the necessary conditions to facilitate the immersion in the virtual environment and the performance simulation very close to the real context.

To assess the program effectiveness we used the Wisconsin Card Sorting Test (WCST), Wechsler Adult Intelligence Scale (WAIS-III) sub-test, Stroop Test, and The Subjective Scale to Investigate Cognition in Schizophrenia (SSTICS) – all of them applied pre and post program. We decided to ally objective measure tools (neuropsychologic tests WAIS-III, WCST, and Stroop Test) with subjective measure tools (SSTICS permits analysing the participants subjective assessment in terms of their daily cognitive functioning, based on their day-to-day activities performance self perception) in order to enhance the results reliability, and the analysis extent.

Table 1. *WAIS III* Sub-testes *Results (before and after the intervention).*

Item	Stage	x	s	z	p	Differences	(n=14)
Picture Completion		18,14	3,94	-2,476	0,013*	Negatives	3
		20,64	2,30			Positives	10
Vocabulary		39,71	12,49	-2,171	0,030*	Negatives	3
		44,14	15,27			Positives	11
Digit Symbol - Coding		48,93	12,66	-1,571	0,116 NS	Negatives	4
		50,14	17,96			Positives	10
Similarities		16,36	6,50	-2,426	0,015*	Negatives	2
		20,29	7,01			Positives	11
Block Design		34,64	12,99	-3,112	0,002**	Negatives	1
		42,29	12,70			Positives	12
Arithmetic		9,29	4,68	-2,720	0,007**	Negatives	1
		12,07	4,71			Positives	11
Matrix Reasoning		12,14	5,54	-2,849	0,004**	Negatives	1
		16,86	5,92			Positives	12
Information		13,71	6,17	-1,847	0,065 NS	Negatives	1
		14,79	5,94			Positives	9
Picture Arrangement		10,43	5,95	-1,980	0,048*	Negatives	2
		12,43	5,69			Positives	10
Comprehension		16,86	7,75	-1,023	0,306 NS	Negatives	4
		17,71	8,76			Positives	8
Digit Span		15,79	3,36	-2,549	0,011*	Negatives	2
		19,07	4,50			Positives	12
Symbol Search		24,57	6,64	-2,633	0,008**	Negatives	2
		28,36	5,33			Positives	11
Letter-Number Sequencing		8,14	2,88	-2,051	0,040*	Negatives	3
		10,07	3,54			Positives	9
Object Assembly		30,64	10,52	-1,508	0,32 NS	Negatives	5
		34,00	9,58			Positives	8

$^*p<0{,}050$ $^{**}p<0{,}010$

3. RESULTS

Table 1 presents WAIS III pre and post subtest results. Statistic analysis reveals a significant increase in the scores of Picture Completion, Vocabulary, Similarities, Picture Arrangement, Digit Span, Letter-Number Sequencing ($p<0{,}050$), Block Design, Arithmetic, Matrix Reasoning, and Symbol Search ($p<0{,}010$). In what concerns the scores on Digit Symbol – Coding, Information, Comprehension, and Object Assembly significant differences were not identified.

Results point out as well (Table 2) that at the end of the program individuals presented a significantly inferior number of errors ($p<0{,}010$) and of perseverative errors in *Wisconsin Card Sorting Test* ($p<0{,}050$). They have completed a significantly major number of categories ($p<0{,}050$). Significant differences on correct answers were not identified.

Table 2. *Wisconsin Card Sorting Test Results (before and after the intervention).*

Item	Stage	x	s	z	p	Differences	(n=14)
Correct Responses Trials	Pre	75,36	11,39	-0,251	0,802 NS	Negatives	6
	Post	73,71	9,41			Positives	8
Number of Errors	Pre	45,86	18,84	-2,691	0.007**	Negatives	11
	Post	31,79	20,18			Positives	2
Non-perseverative errors	Pre	21,43	8,62	-1,477	0,140 NS	Negatives	9
	Post	17,29	12,07			Positives	5
Perseverative answers	Pre	32,71	19,87	-2,168	0.030*	Negatives	10
	Post	19,93	15,17			Positives	3
Perseverative errors	Pre	24,43	15,41	-2,136	0.033*	Negatives	10
	Post	14,64	11,26			Positives	4
Categories	Pre	4,21	1,67	-2,401	0.016*	Negatives	1
	Post	5,29	1,64			Positives	8

*p<0,050 **p<0,010

Results presented in Table 3 indicate that individuals demonstrated a significantly better performance in the Word, and Word-Color ($p<0{,}010$) of the Stroop subtest. There are not significant differences on the Colors and Interferences score.

Table 3. *Stroop Test Results (before and after the intervention).*

Item	Stage	x	s	z	p	Differences	(n=14)
Word	Pre	33,43	8,82	-2,633	0,008**	Negatives	2
	Post	39,14	7,85			Positives	10
Color	Pre	34,93	7,44	-0,565	0,571	Negatives	5
	Post	36,00	6,42			Positives	9
Word-Color	Pre	33,07	6,34	-3,206	0,001**	Negatives	1
	Post	39,36	7,74			Positives	13
Interference	Pre	48,79	8,44	-0,210	0,834	Negatives	6
	Post	49,43	8,92			Positives	7

*p<0,050 **p<0,010

Finally, Table 4 shows the results on the participants subjective perception in terms of their own cognitive performance. In the SSICS the higher scores refer to the difficulties felt in cognitive functioning. In this terms, we may verify that after the intervention program individuals obtained significantly inferior results in what concerns the total score ($p<0{,}010$) and almost assessed dimensions: explicit memory and global perception ($p<0{,}010$), working memory, attention, executive functioning, and language ($p<0{,}050$). Only in praxia dimension there was no significant differences.

Table 4. *Subjective Scale to Investigate Cognition in Schizophrenia Results (before and after the intervention).*

Item	Stage	x	s	z	p	Differences	(n=14)
Working Memory	Pre	5.86	1.29	-2,223	0.026*	Negatives	8
	Post	4.79	1.19			Positives	2
Explicit Memory	Pre	21.21	3.83	-2,769	0.006**	Negatives	10
	Post	18.50	3.06			Positives	1
Attention	Pre	15.86	3.18	-2,419	0.016*	Negatives	10
	Post	13.21	2.99			Positives	3
Executive Functioning	Pre	8.64	2.50	-2,023	0.043*	Negatives	8
	Post	7.07	1.63			Positives	1
Language	Pre	3.00	0.96	-2,333	0.020*	Negatives	6
	Post	2.21	0.80			Positives	0
Praxia	Pre	2.00	0.96	-1,830	0.059 NS	Negatives	6
	Post	1.64	0.93			Positives	1
Total Score	Pre	55.93	9.30	-2,922	0.003**	Negatives	12
	Post	47.29	7.35			Positives	2

*p<0,050 **p<0,010

4. CONCLUSIONS

Results identified significant differences ($p<0.05$) between pre and post tests in the subjective and objective assessed cognitive dimensions. There was a significant improvement in the cognitive performance, namely in the ability of perceptual organization (Picture Completion, Block Design and Matrix Reasoning), in working memory (Arithmetic, Digit Span and Letter–Number Sequencing), processing speed (Digit Symbol, Coding and Symbol Search), attention (Stroop Test), and the executive functions (WCST). It was also identified that the intervention program appeared to have improved the verbal comprehension (Vocabulary, and Similarities) despite we did not found significant differences in the Information sub-test.

Simultaneously the relapse and re-hospitalized rate (6,7%), drop out rate (0%), attendance rate (91%), and punctuality rate (85%) verified are the example of the high level of participants motivation and satisfaction, which has to be considered as an other success indicator.

The results point out that virtual reality technology and IPT may be a significant resource and intervention methodology in the promotion of cognitive competencies in people with psychiatric disabilities. However, considering that this research represents only a pilot study (obviously with some limitations, such as the inexistence of control group or the reduced number of participants), it is essential that further investigation is made on this field.

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Neuropsychological assessment using the virtual reality cognitive performance assessment test

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ABSTRACT

The traditional approach to assessing neurocognitive performance makes use of paper and pencil neuropsychological assessments. This received approach has been criticized as limited in the area of ecological validity. The newly developed Virtual Reality Cognitive Performance Assessment Test (VRCPAT) focuses upon enhanced ecological validity using virtual environment scenarios to assess neurocognitive processing. The VRCPAT battery and a neuropsychological assessment were conducted with a sample of healthy adults. Findings suggest 1) good construct validity for the Memory Module; and 2) that increase in stimulus complexity and stimulus intensity can manipulate attention performance within the Attention Module.

1. INTRODUCTION

While standard neuropsychological measures have been found to have adequate predictive value, their ecological validity may diminish predictions about real world functioning (Chaytor et al., 2006; Farias, Harrell, Neumann, & Houtz, 2003; Gioia & Isquith, 2004; Odhuba et al., 2005). Traditional neurocognitive measures may not replicate the diverse environment that in which persons live. Additionally, standard neurocognitive batteries tend to examine isolated components of neuropsychological ability, which may not accurately reflect distinct cognitive domains (Parsons et al., 2005). Virtual Reality (VR) technology is increasingly being recognized as a useful tool for the study, assessment, and rehabilitation of cognitive processes and functional abilities. The ability of VR to create dynamic, immersive, three-dimensional stimulus environments, in which all behavioral responding can be recorded, offers assessment and rehabilitation options that are not available using traditional assessment methods. In this regard, VR applications are now being developed and tested which focus on component cognitive processes including: attention processes (Parsons et al., in press; Rizzo et al., 2006), spatial abilities (Parsons et al., 2004), memory (Matheis et al., 2007), and executive functions (Baumgartner et al., 2006; Elkind et al., 2001). The increased ecological validity of neurocognitive batteries that include assessment using VR scenarios may aid differential diagnosis and treatment planning.

The Virtual Reality Cognitive Performance Assessment Test (VRCPAT) project focuses on the refined analysis of neurocognitive testing using a virtual environment to assess recall of targets delivered within the context of a virtual city. Herein we report on two phases of VRCPAT development: 1) the psychometric properties of data gained from human pilot testing with the VRCPAT; and 2) Attentional processing within the virtual environment.

2. METHODS: EXPERIMENT 1

We acquired data on the implementation of a virtual reality (i.e. VRCPAT) in a normative sample that also received a traditional paper and pencil battery. Because the VRCPAT was designed to tap very specific neurocognitive systems and not to mirror a traditional paper-and-pencil battery, our goal is not to replace the traditional battery for all neurocognitive domains. We aim to assess the psychometric properties of the VR and paper-and-pencil measures. Hence, scores were correlated with demographic and other performance tests measures administered. Standard correlational analyses using a brief demographic survey and pencil-and-

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paper cognitive tests aid our initial assessment of both the concurrent and divergent validity properties of this form of assessment.

Our plan for the development and implementation of the VRCPAT's psychometric properties involved systematic refinement analyses that acted as a component of an ongoing dialectic between measurement and substantive research. We aim to make the VRCPAT to be a well developed measure that facilitates substantive advances. First, we identified the VRCPAT's hierarchical or aggregational structure. Next, we established the internal consistency of the VRCPAT's unidimensional facets (memory domain). We also determined the content homogeneity of each of the VRCPAT's unidimensional facets. The establishment of the VRCPAT's psychometric properties removed the possibility that results reflect correlates of the target construct (memory and/or attention) but are not prototypic of it. We also assessed the level to which all aspects of the target construct (memory) is under- or overrepresented in the VRCPAT's composition, and assess whether the experience of some aspects of the virtual environment introduced variance unrelated to the target construct.

2.1 Participants

The study sample included 20 healthy subjects (Age, mean = 24.45, SD = 3.05; 50 % male; and Education, mean = 14.05, SD = 0.51). Strict exclusion criteria were enforced so as to minimize the possible confounding effects of comorbid factors known to adversely impact cognition, including psychiatric (e.g., mental retardation, psychotic disorders, diagnosed learning disabilities, Attention-Deficit/Hyperactivity Disorder, and Bipolar Disorders, as well as substance-related disorders within two years of evaluation) and neurologic (e.g., seizure disorders, closed head injuries with loss of consciousness greater than 15 minutes, and neoplastic diseases) conditions. Subjects were comparable in age, education, ethnicity, sex, and self-reported symptoms of depression.

2.2 Procedure

After providing informed written consent, all participants were administered the VRCPAT as part of a larger neuropsychological test battery. The VRCPAT is a 15-minute measure, in which participants (referred to as "users" in the following text) then go through the following steps: Acquisition Phase – Users are presented with 10 pieces of language-based information to be learned, without any context for what they will need to do with this information. The information stimuli is primarily language based (i.e., blue car with bullet holes in windshield only, intact barrel with U.S. Army stenciled on it, red shipping container with numbers 7668, etc.), although stimuli includes minimal imagery to provide opportunities for more context relevant stimulus creation (e.g., a crate with Iraqi flag in upper side corner (with just image of Iraqi flag presented)). The acquisition phase is initially standardized to three one-minute trials. At the end of each trial, users are then asked to name the objects that they studied as an assessment of initial declarative recall memory. It should be noted here that the item pool of stimuli that is being used in the formal tests was generated during the initial development phase. At that time, various stimulus combinations were piloted (not using VR) with users to determine "memorability" to inform final selection of stimuli that is being used in the formal VR test. Informal exploration of image-based stimuli for later development of a pure object-based visual stimulus MM test has occurred concurrently with verbal tests, using pictures of objects similar to the language stimuli.

2.2.1 VR Interface and Task Training Phase. After users are given the three one-minute trials to "memorize" the stimuli, a brief "interface training" period then occurs in which users become familiar with their objective, the controls of the game pad navigation interface and head-mounted display (HMD). The task is read aloud by the investigator and contains specific instructions for how to proceed through the VE and how to record images of each target object. Users are told that they will need to go to each target zone in sequence (guided by an American soldier), and at each zone, two of the items that they had memorized previously will be present somewhere in the environment from that vantage point. Upon finding the items, they should align the cross hairs with that object and press the response button to record (or "collect" them). Users have one minute to spend within each target zone and scan for the relevant memorized target items. If they find the target items in less than the one-minute period, they must wait for time to expire and follow their guide to the next zone. If the user does not find both objects in a target zone by the time that the one-minute period has elapsed, an alarm sounds and a voice tells the user to move to the next zone and seek out the two objects located there. To minimize guessing by subjects that hit the response button on all possible target objects, subjects are told that they have a limit of two button presses per zone.

The VE is designed to resemble and Iraqi city and the location of this task training phase also serves as the starting point for the users. The environment contains people (of various ages and gender) dressed in culturally appropriate clothing, a market place, American soldiers, various moving civilian vehicles, animals, buildings and street signs and a host of other objects (i.e., wooden barrels, crates, containers, etc.). Users are given as much time as needed to explore a limited area of the environment. This exploration area is determined by the experimenter. During this phase, the investigator can informally present verbal guidance to the users in order to help them to become familiar with the interface navigation, response button and HMD viewing parameters. This phase is designed to teach the interface controls to the user, so that performance on the VE navigation and object selection interaction tasks are minimally influenced or distracted away from the resulting memory assessment in the retrieval phase that follows.

2.2.2 Retrieval Phase. Once users indicate that they are comfortable within the VE and can demonstrate comprehension of the navigation interface and targeting procedure, the investigator asks if there are any questions. If so, clarification and coaching occur until the user can fully comprehend the task. If not, the investigator starts the exercise and observes the user. Should problems occur, the investigator can verbally coach the user until issues are resolved.

2.2.3 Debriefing Phase. During this phase, users are asked to recall the original list of stimuli and at which target zones they were found. The performance measures that are derived from this test include: number of correct hits, false hits, time to successfully complete per target zone, time to complete overall. A trained research assistant administered all psychometric tests. The Simulator Sickness Questionnaire (Kennedy et al., 1992; SSQ) was used to determine whether the participant felt sick as a result of the VR experience.

The broader neuropsychological battery contained the following tests: 1) Controlled Oral Word Association Test (COWAT-FAS; Benton, Hamsher, & Sivan, 1994; Gladsjo et al., 1999); 2) animal fluency (Gladsjo et al., 1999); 3) Digit Symbol Coding, Digit Span (Forward and Backward), and Letter-Number Sequencing from the Wechsler Adult Intelligence Scale –Third edition (WAIS-III; Psychological Corporation, 1997); 4) Trail Making Test Parts A and B (TMT; Heaton, Grant, & Matthews, 1991; Reitan & Wolfson, 1985); 5) Hopkins Verbal Learning Test – Revised (HVLT-R; Brandt & Benedict, 2001); 6) Brief Visuospatial Memory Test – Revised (BVMT-R; Benedict, 1997); 7) Stroop Color and Word Test (Golden, 1978); 8); Wechsler Test of Adult Reading (WTAR; Wechsler, 2001).

3. RESULTS: EXPERIMENT 1

Given the similarity of participants in terms of age, sex, education, immersiveness, and ethnicity, no correction for these variables was employed. Notably, none of the participants reported simulator sickness following VR exposure as measured by the SSQ. To provide preliminary data to support the validity of the VRCPAT as a measure of learning and memory, recall indices from the VRCPAT and traditional neuropsychological tests were correlated. Indices were developed from linear composites derived from z-score transformations. Specifically, Pearson correlation analyses were used to compare recall from the VRCPAT with linear composites derived from traditional neuropsychological measures.

3.1 Convergent Validity Tests

Whilst the VRCPAT Total Memory Score was significantly correlated with composites derived from established measures of learning and memory, it did not correlate with possibly confounded variables (i.e., Executive Functions; Attention; and Processing Speed) drawn from traditional neuropsychological measures that are not assessments of learning and memory. Hence, the results indicated that the VRCPAT correlated significantly with the traditional neuropsychological Learning Composite (HVLT Trials 1-3; and BVMT Trials 1-3; $r = 0.68$, $p < 0.001$), with 46% variance shared between the two indices. The results indicated that the VRCPAT also correlated significantly with the traditional neuropsychological Memory Composite (HVLT Total Recall after a Delay; and BVMT Total Recall after a Delay; $r = 0.67$, $p < 0.001$), with 45% variance shared between the two indices.

3.2 Discriminant Validity Tests

As expected, there were no significant correlations between VRCPAT measures and the following neuropsychology test composites: Executive Functions Composite; Attention Composite; or Processing Speed Composite. Hence, each of the discriminant validity significance tests were as predicted, that is, did not correlate with theoretically unrelated abilities. Although validity coefficients drawn from composites may not meet validity expectations it may still be the case that individual measures account for some of the trait variance. Therefore, we assessed the measures both as composites and individually. As such, we compared the VRCPAT with the actual neuropsychological tests (used to derive the Learning Composite and the Memory Composite). Analysis of the relations between the VRCPAT Total Memory Score and the actual learning and memory tests revealed significant correlations for each of the convergent validity significance tests, in accordance with prediction. For correlations between the VRCPAT and traditional psychometric measures we only considered those correlations that met the criterion of $p < .05$ to be meaningful. Given our small sample size we kept p at this level, despite the risk of Type I error with multiple correlations. All of our significant correlations were associated with at least moderate effect sizes.

4. METHODS: EXPERIMENT 2

The following two VR-based attentional measures were designed and evolved following iterative user testing: 1) Fixed Position in the Virtual City Test (See Figure 1); and 2) Humvee Attention Task.

Figure 1. *Fixed Position in the Virtual City.*

Figure 2. *Humvee Attention Task.*

4.1.1 Fixed Position in the Virtual City Test. In this scenario subjects were given both a selective attention and a working memory task. For the selective attention portion, each subject listened to a virtual trainee as the trainee classified passing vehicles. For the evaluation, the virtual trainee reported either "US military", "Iraqi police", "Iraqi civilian" or "possible insurgent". The subject was to tell the new recruit whether he was correct or incorrect. For the working memory portion, subjects were presented a series of single digit numbers. Subjects listened for the first two numbers, added them up, and reported the answer to the examiner. When the subject heard the next number, s/he added it to the one presented right before it. Subjects continued to add the next number to each preceding one. Subjects were not being asked to give examiner a running total, but rather the sum of the last two numbers that were presented. For example, if the first two numbers were '5' and '7,' subject would say '12.' If the next number were '3,' subject would say '10.' Then if the next number were '2,' subject would say '5' because the last two numbers presented were 3 and 2. See Table 1 for descriptives.

4.1.2 HUMVEE Attention Task. The Humvee scenario assessed attention within both "safe" and "ambush" settings: 1) start section; 2) palm ambush; 3) safe zone; 4) city ambush; 5) safe zone; 6) bridge ambush. The task involved the presentation of a four-digit number that was superimposed on the virtual windshield (of the Humvee) while the subject drove the Humvee. Each four-digit number was presented for approximately 300 ms and was randomly selected by the computer from a database of prescreened numbers. Subjects were required to say the number out loud immediately after it appeared on the screen while the Humvee continued driving. An examiner will recorded the responses. See Table for descriptives of Humvee Attention Test.

The design consists of six Humvee attention conditions:

i) *Fixed Position: 2.0 second condition (Start Section).* In this condition, the four-digit number always appeared in a *fixed central* location on the "windshield." The numbers were presented at 2.0 second intervals. This occurred in the "Start Section" and ended just before the "Palm Ambush."

ii) *Fixed Position: 1.5 second condition (Palm Ambush).* The procedure for this condition was identical to the "Fixed Position" condition described previously except that the numbers were presented at 1.5 second intervals. This occurred in the "Palm Ambush" section and ended just before the "Safe Zone" section.

iii) *Fixed Position: 0.725 second condition (Safe Zone).* The procedure for this condition was identical to the "Fixed Position" condition described previously except that the numbers were presented at 0.725 second intervals. This occurred in the "Safe zone" and ended just before the "City Ambush" section.

iv) *Random Position: 2.0 second condition (City Ambush).* The procedure for this condition is similar to the "Fixed Position" condition with the exception that the numbers appear *randomly* throughout the "windshield" rather than in one fixed central location. The numbers were presented at 2.0 second intervals. This occurred in the "City Ambush" and ended just before the "Safe Zone".

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v) Random Position: 1.5 second condition (Safe Zone). The procedure for this condition is similar to the preceding "Random Position" condition except that the numbers were presented at 1.5 second intervals. This occurred in the "Safe Zone" and ended just before the "Bridge Ambush".

vi) Random Position: 0.725 second condition (Bridge Ambush). The procedure for this condition is similar to the preceding "Random Position" condition except that the numbers were presented at 0.725 second intervals. This occurred in the "Bridge Ambush".

5. RESULTS: EXPERIMENT 2

To examine scenario differences, one-way ANOVAs were performed, comparing attentional performance in simple stimulus presentations (Mean = 43.63; SD = 8.91) versus complex stimulus presentations (Mean = 34.63; SD = 6.86). The results indicated that the increase in stimulus complexity caused a significant decrease in performance on attentional tasks ($F = 5.12$; $p = 0.04$). To examine scenario differences, we compared attentional performance in low intensity (Mean = 40.01; SD = 4.06) versus high intensity (Mean = 9.25; SD = 3.70) presentations. The results indicated that the increase in stimulus intensity caused a significant decrease in performance on attentional tasks ($t = 9.83$; $p = 0.01$). Given the small sample size, we decided to not assess the construct validity of the VRCPAT Attention Modules. Hence, no attempts were made to assess correlations between standard paper and pencil tests and VRCPAT.

6. DISCUSSION

6.1 Experiment 1

The results of this study indicate that: 1) VRCPAT memory measures correlated significantly with scores from the memory measures drawn from the traditional neuropsychological test battery; 2) VRCPAT memory scores did not correlate with non-memory measures drawn from the traditional neuropsychological test battery. Additionally, no negative side effects were associated with use of the VRCPAT. The establishment that the VRCPAT's memory measures correlated significantly with scores from the memory measures drawn from the traditional neuropsychological test battery but not with non-memory measures removed the possibility that results reflected correlates of the non-target construct (i.e. processing speed; executive function).

Our goal was to conduct an initial pilot study of a VRCPAT that employs a standard neuropsychological battery for the assessment of normal participants. We believe that this goal was met. We recognize, however, that the current findings are only a first step in the development this tool. Many more steps need to be taken in order to continue the process of test development and to fully establish the VRCPAT as a measure that contributes to existing assessment procedures for the diagnosis of memory decline. Whilst the VRCPAT as a measure needs to be fully validated, current findings provide preliminary data regarding the validity of the virtual environment as a memory measure. The VRCPAT was correlated with widely used memory assessment tools. Nevertheless, the fairly small sample size requires that the reliability and validity of the VRCPAT be established using a larger sample of well-matched participants. This will ensure that current findings are not a sample size related anomaly. Finally, the ability of the VRCPAT to accurately classify participants not involved in the initial validation study will need to be examined for cross-validation purposes.

6.2 Experiment 2

Our goal was to conduct an initial pilot study of the general usability of the VRCPAT Attention Module scenarios. We aimed at assessing whether the increase in stimulus complexity would result in a significant decrease in performance on attentional tasks. We also wanted to see whether an increase in stimulus intensity would result in a significant decrease in performance on attentional tasks. We believe that this goal was met as the study results indicated that: (1) the increase in stimulus complexity caused a significant decrease in performance on attentional tasks; and 2) the increase in stimulus intensity caused a significant decrease in performance on attentional tasks.

Our findings should be understood in the context of some limitations. First, these findings are based on a fairly small sample size. As a necessary next step, the reliability and validity of the test needs to be established using a larger sample of participants. This will ensure that the current findings are not an anomaly due to sample size. Additionally, the diagnostic utility of this attention assessment tool must be determined. The ability of the VRCPAT's Attention Module to accurately classify participants into attention impaired and attention intact groups based on carefully established critical values must be evaluated. This will involve the generation of specific cut-off points for classifying a positive or negative finding. The VRCPAT Attention

Module's prediction of attentional deficits will need to be evaluated by the performance indices of sensitivity, specificity, predictive value of a positive test, and predictive value of a negative test.

In sum, manipulation of stimulus complexity and intensity in the VRCPAT's Attention Module caused a significant differences in performance on attentional tasks. Complementary comparisons of the VRCPAT's Attention Module with behavioral and neurocognitive tests developed to assess attentional processing are also warranted to determine the construct validity of the test.

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Virtual reality Post Traumatic Stress Disorder (PTSD) exposure therapy results with active duty Iraq war combatants

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ABSTRACT

Post Traumatic Stress Disorder (PTSD) is reported to be caused by traumatic events that are outside the range of usual human experience including (but not limited to) military combat, violent personal assault, being kidnapped or taken hostage and terrorist attacks. Initial data suggests that at least 1 out of 6 Iraq War veterans are exhibiting symptoms of depression, anxiety and PTSD. Virtual Reality (VR) delivered exposure therapy for PTSD has been used with reports of positive outcomes. The aim of the current paper is to present the rationale and brief description of a *Virtual Iraq* PTSD VR therapy application and present initial findings from its use with PTSD patients. Thus far, *Virtual Iraq* consists of a series of customizable virtual scenarios designed to represent relevant Middle Eastern VR contexts for exposure therapy, including a city and desert road convoy environment. User-centered design feedback needed to iteratively evolve the system was gathered from returning Iraq War veterans in the USA and from a system deployed in Iraq and tested by an Army Combat Stress Control Team. Results from an open clinical trial at San Diego Naval Medical Center of the first 18 treatment completers indicate that 14 no longer meet PTSD diagnostic criteria at post-treatment, with only one not maintaining treatment gains at 3 month follow-up. Clinical tests are also currently underway at Ft. Lewis, Emory University, Weill Cornell Medical College, Walter Reed Army Medical Center and 10 other sites. Other sites are preparing to use the application for a variety of PTSD and VR research purposes.

1. INTRODUCTION

War is perhaps one of the most challenging situations that a human being can experience. The physical, emotional, cognitive and psychological demands of a combat environment place enormous stress on even the best-prepared military personnel. The high level of stress that is naturally experienced in combat typically results in a significant percentage of soldiers at risk for developing Post Traumatic Stress Disorder (PTSD) upon the return home. According to the DSM-IV (1994), PTSD is caused by traumatic events that are outside the range of usual human experiences including (but not limited to) military combat, violent personal

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assault and rape, being kidnapped or taken hostage, terrorist attacks, and automobile accidents. The disorder also appears to be more severe and longer lasting when the event is caused by human means and design (bombings, shootings, combat, etc.). Such incidents would be distressing to almost anyone, and is usually experienced with intense fear, terror, and helplessness. Typically, the initiating event involves actual or threatened death or serious injury, or other threat to one's physical integrity; or the witnessing or awareness of an event that involves death, injury, or a threat to the physical integrity of another person. The essential feature of PTSD is the development of characteristic symptoms that may include: intrusive thoughts, nightmares and flashbacks, avoidance of reminders of the traumatic event, emotional numbing, and hyper-alertness. Symptoms of PTSD are often intensified when the person is exposed to stimulus cues that resemble or symbolize the original trauma in a *non-therapeutic* setting. Such *uncontrolled* cue exposure may lead the person to react with a survival mentality and mode of response that could put the patient and others at considerable risk

In the early 21st century the conflicts in Iraq and Afghanistan again drew US military personnel into combat. The Iraq/Afghanistan combat theatres, with their ubiquitous battlefronts, ambiguous enemy identification, and repeated extended deployments has produced significant numbers of returning American Service Members (SMs) reporting symptoms that are congruent with the diagnosis of PTSD and other mental disorders. In the first systematic study of mental health problems due to these conflicts, "…The percentage of study subjects whose responses met the screening criteria for major depression, generalized anxiety, or PTSD was significantly higher after duty in Iraq (15.6 to 17.1 percent) than after duty in Afghanistan (11.2 percent) or before deployment to Iraq (9.3 percent)" **(**Hoge et al., 2004). These estimates were made before the violence escalated even further and other reports since the original Hoge et al. publication, have indicated equivalent or higher numbers of returning military SMs and veterans reporting positive for PTSD and symptoms of other forms of mental disorders (Hoge et al., 2006; Seal et al., 2007; Tanielian et al., 2008).

Among the many approaches that have been used to treat PTSD, cognitive-behavioral treatment (CBT) with Prolonged Exposure (PE) appears to have the best-documented therapeutic efficacy (Bryant, 2005; Rothbaum et al., 2000, 2001, 2002; Van Etten & Taylor, 1998). PE is a form of individual psychotherapy based on Foa and Kozak's (1986) emotional processing theory, which posits that PTSD involves pathological fear structures that are activated when information represented in the structures is encountered. These fear structures are composed of harmless stimuli that have been associated with danger and are reflected in the belief that the world is a dangerous place. This belief then manifests itself in cognitive and behavioral avoidance strategies that limit exposure to potentially corrective information that could be incorporated into and alter the fear structure. Successful treatment requires emotional processing of the fear structures in order to modify their pathological elements so that the stimuli no longer invoke fear. Emotional processing first requires accessing and activating the fear structure associated with the traumatic event and then incorporating information that is not compatible with it. Imaginal exposure entails engaging mentally with the fear structure through repeatedly revisiting the traumatic event in a safe environment. In practice, a person with PTSD typically is guided and encouraged by the clinician gradually to *imagine, narrate and emotionally process* the traumatic event within the safe and supportive environment of the clinician's office. This approach is believed to provide a low-threat context where the patient can begin to therapeutically process the emotions that are relevant to the traumatic event as well as de-condition the learning cycle of the disorder via a habituation/extinction process. Expert treatment guidelines for PTSD published for the first time in 1999 recommended that CBT with PE should be the first-line therapy for PTSD (Foa et al., 1999). The comparative empirical support for exposure therapy was also recently documented in a review by the Institute of Medicine at the National Academies of Science (sponsored by the U.S. Department of Veterans Affairs) of 53 studies of pharmaceuticals and 37 studies of psychotherapies used in PTSD treatment (Institute of Medicine, 2007). The report concluded that while there is not enough reliable evidence to draw conclusions about the effectiveness of most PTSD treatments, there is sufficient evidence to conclude that exposure therapies are effective in treating people with PTSD.

While the efficacy of imaginal PE has been established in multiple studies with diverse trauma populations, many patients are unwilling or unable to effectively visualize the traumatic event. This is a crucial concern since avoidance of cues and reminders of the trauma is one of the cardinal symptoms of the DSM diagnosis of PTSD. In fact, research on this aspect of PTSD treatment suggests that the inability to emotionally engage (*in imagination*) is a predictor for negative treatment outcomes (Jaycox et al., 1998). To address this problem, researchers have recently turned to the use of Virtual Reality (VR) to deliver exposure therapy (VRET) by immersing clients in simulations of trauma-relevant environments in which the emotional intensity of the scenes can be precisely controlled by the clinician. In this fashion, VRET offers a way to circumvent the natural avoidance tendency by directly delivering multi-sensory and context-relevant cues that evoke the trauma without demanding that the patient actively try to access his/her experience through effortful memory retrieval. Within a VR environment, the hidden world of the patient's imagination is not exclusively relied upon and VRET may also offer an appealing, non-traditional treatment approach that is perceived with less stigma by "digital generation" SMs and veterans who may be reluctant to seek out what they perceive as traditional talk therapies.

The first effort to apply VRET began in 1997 when researchers at Georgia Tech and Emory University began testing the *Virtual Vietnam* VR scenario with Vietnam veterans diagnosed with PTSD. This occurred over 20 years after the end of the Vietnam War. During those intervening years, in spite of valiant efforts to develop and apply traditional psychotherapeutic and pharmacological treatment approaches to PTSD, the progression of the disorder in some veterans significantly impacted their psychological well-being, functional abilities and quality of life, as well as that of their families and friends. This initial effort yielded encouraging results in a case study of a 50-year-old, male Vietnam veteran meeting *DSM* criteria for PTSD (Rothbaum et al., 1999). Results indicated post-treatment improvement on all measures of PTSD and maintenance of these gains at a 6-month follow-up, with a 34% decrease in clinician-rated symptoms of PTSD and a 45% decrease on self-reported symptoms of PTSD. This case study was followed by an open clinical trial with Vietnam veterans (Rothbaum et al., 2001). In this study, 16 male veterans with PTSD were exposed to two head-mounted display-delivered virtual environments, a virtual clearing surrounded by jungle scenery and a virtual Huey helicopter, in which the therapist controlled various visual and auditory effects (e.g. rockets, explosions, day/night, shouting). After an average of 13 exposure therapy sessions over 5-7 weeks, there was a significant reduction in PTSD and related symptoms. Similar positive results were reported by Difede et al. (2002) for PTSD that resulted from the attack on the World Trade Center in a case study using VRET with a patient who had failed to improve with traditional exposure therapy. This group has recently reported positive results from a wait-list controlled study using the same World Trade Center VR application (Difede et al., 2007). The VR group demonstrated statistically and clinically significant decreases on the "gold standard" Clinician Administered PTSD Scale (CAPS) relative to both pre-treatment and to the wait-list control group with a between-groups post treatment effect size of 1.54. Seven of 10 people in the VR group no longer carried the diagnosis of PTSD, while all of the wait-list controls retained the diagnosis following the waiting period and treatment gains were maintained at 6-month follow-up. Also noteworthy was the finding that five of the 10 VR patients had previously participated in imaginal exposure treatment with no clinical benefit. Such initial results are encouraging and suggest that VR may be a useful component within a comprehensive treatment approach for persons with combat/terrorist attack-related PTSD.

2. DESIGN OF THE *VIRTUAL IRAQ* EXPOSURE THERAPY SYSTEM

The University of Southern California's Institute for Creative Technologies (ICT), in collaboration with the authors of this paper, have partnered on a project funded by the Office of Naval Research (ONR), the U.S. Army Research, Development and Engineering Command (RDECOM) and the Telemedicine and Advanced Technology Research Center (TATRC) to develop a series of VR exposure environments known as *Virtual Iraq*. This VR treatment system was originally constructed by recycling virtual art assets that were initially designed for the commercially successful X-Box game and U.S. Army-funded combat tactical simulation trainer, *Full Spectrum Warrior*. Other existing and newly created art and technology assets available to ICT have been integrated into this continually evolving application. The presence of ICT expertise in designing combat simulations and an interdisciplinary collaboration with leading experts and scientists in the field of PTSD has led to the opportunity to apply VR for this relevant clinical challenge, albeit within a tighter timeframe than the technology allowed for Vietnam era veterans with PTSD.

Virtual Iraq consists of Middle Eastern themed city and desert road environments (See Figures 1-3) and was designed to resemble the general contexts that most SMs experience during deployment to Iraq. The 18 square block "City" setting has a variety of elements including a marketplace, desolate streets, old buildings, ramshackle apartments, warehouses, mosques, shops and dirt lots strewn with junk. Access to building interiors and rooftops is available and the backdrop surrounding the navigable exposure zone creates the illusion of being embedded within a section of a sprawling densely populated desert city. Vehicles are active in streets and animated virtual pedestrians (civilian and military) can be added or eliminated from the scenes. The software has been designed such that users can be teleported to specific locations within the city, based on a determination as to which environments most closely match the patient's needs, relevant to their individual trauma-related experiences. The "Desert Road" scenario consists of a roadway through an expansive desert area with sand dunes, occasional areas of vegetation, intact and broken down structures, bridges, battle wreckage, a checkpoint, debris and virtual human figures. The user is positioned inside of a HUMVEE that supports the perception of travel within a convoy or as a lone vehicle with selectable positions as a driver, passenger or from the more exposed turret position above the roof of the vehicle. The number of soldiers in the cab of the HUMVEE can also be varied as well as their capacity to become wounded during certain attack scenarios (e.g., IEDs, rooftop and bridge attacks). Both the city and HUMVEE scenarios are adjustable for time of day or night, weather conditions, nightvision, illumination and ambient sound (wind, motors, city noise, prayer call, etc.). As well, we now have created visual elements that can be selected to resemble Afghanistan scenery and architecture in an effort to broaden the relevance of the application for a wider range of SMs.

Figures 1-3. *Virtual Iraq City, Desert Road and Virtual Afghanistan mountain scenes.*

Users can navigate in both scenarios via the use of a standard gamepad controller, although we have recently added the option for a replica M4 weapon with a "thumb-mouse" controller that supports movement during the city foot patrol. This was based on repeated requests from Iraq experienced SMs who provided frank feedback indicating that to walk within such a setting without a weapon in-hand was completely unnatural and distracting! However, there is no option for firing a weapon within the VR scenarios. It is our firm belief that the principles of exposure therapy are incompatible with the cathartic acting out of a revenge fantasy that a responsive weapon might encourage. In addition to the visual stimuli presented in the VR Head-Mounted Display (HMD), directional 3D audio, vibrotactile and olfactory stimuli can be delivered into the VR scenarios in realtime by the clinician. The presentation of additive, combat-relevant stimuli in the VR scenarios can be controlled via a separate "Wizard of Oz" control panel, while the clinician is in full audio contact with the patient. This clinical "interface" is a key feature that provides a clinician with the capacity to customize the therapy experience to the individual needs of the patient. The patient can be placed by the clinician in VR scenario locations that resemble the setting in which the trauma-relevant events occurred and modify ambient light and sound conditions to match the patients description of their experience. The clinician can then gradually introduce and control real time trigger stimuli (visual, auditory, olfactory and tactile), via the clinician's interface, as required to foster the anxiety modulation needed for therapeutic habituation and emotional processing in a customized fashion according to the patient's past experience and treatment progress. The clinician interface options have been designed with the aid of feedback from clinicians with the goal to provide a usable and flexible control panel system for conducting thoughtfully administered exposure therapy that can be readily customized to suit the needs of the patient. Such options for real time stimulus delivery flexibility and user experience customization are key elements for these types of VR exposure applications. Details on the equipment needed to run the *Virtual Iraq* system have been detailed in other papers (Rizzo et al., 2006, in press).

3. STATUS OF CURRENT *VIRTUAL IRAQ* RESEARCH

The *Virtual Iraq* scenario is currently being implemented as an exposure therapy tool with active duty SMs and Veterans at Madigan Army Medical Center (MAMC) at Ft. Lewis, WA., the Naval Medical Center-San Diego (NMCSD), Camp Pendleton, Emory University, Walter Reed Army Medical Center (WRAMC), the Weill Medical College of Cornell University and at 14 other VA, Military and University Laboratory sites for VRET research and a variety of other PTSD-related investigations. However, the user-centered design process for optimizing Virtual Iraq for clinical use is noteworthy and will be briefly described before summarizing the status of the initial open-clinical trial results.

3.1 User Centered Feedback from Non-PTSD Service Members

User-Centered tests with early prototypes of the *Virtual Iraq* application were conducted at the NMCSD and within an Army Combat Stress Control Team in Iraq. This informal feedback provided by non-diagnosed Iraq-experienced military personnel provided essential information that fed an iterative design process on the content, realism and usability of the initial "intuitively designed" system. More formal evaluation of the system took place at MAMC from late 2006 to early 2007 (Reger, Gahm, Rizzo, Swanson & Duma, in press). Ninety-three screened SMs (all non-PSTD) evaluated the *Virtual Iraq* scenarios shortly after returning from deployment in Iraq. SMs experienced the city and HUMVEE environments while exposed to scripted researcher-initiated VR trigger stimuli to simulate an actual treatment session. SMs then completed standardized questionnaires to evaluate the realism, sense of "presence" (the feeling of being in Iraq), sensory stimuli, and overall technical capabilities of *Virtual Iraq*. Items were rated on a scale from 0 (Poor) to 10 (Excellent). Qualitative feedback was also collected to determine additional required software improvements. The results suggested that the *Virtual Iraq* environment in its form at the time was realistic and provided a good sense of "being back in Iraq". Average ratings across environments were between adequate and excellent for all evaluated aspects of the virtual environments. Auditory stimuli realism (M=7.9; SD=1.7) and quality (M=7.9; SD=1.8) were rated higher than visual realism (M=6.7; SD=2.1) and quality (M=7.0; SD=2.0). Soldiers had high ratings of the computer's ability to update visual graphics during movement (M=8.4; SD=1.7). The eMagin HMD was reportedly very comfortable (M=8.2; SD=1.7), and the average ratings for the ability to move within the virtual environment was generally adequate or above (M=6.1; SD=2.5). This data, along with the collected qualitative feedback, was used to inform upgrades to the current version of *Virtual Iraq* that is now in clinical use and this "design-collect feedback-redesign" cycle will continue throughout the lifecycle of this project.

3.2 Service Member Acceptance of VR in Treatment

The prior results indicated that the *Virtual Iraq* software was capable of producing the level of "presence" in Iraq-experienced SMs that was believed to be required for exposure therapy. However, successful clinical implementation also requires patients to accept the approach as a useful and credible behavioral health treatment. To address this issue, a survey study with 325 Army SMs from the MAMC/Fort Lewis deployment screening clinic was conducted to assess knowledge of current technologies and attitudes towards the use of technology in behavioral healthcare (Wilson et al., under review). One section of the survey asked these active duty SMs to rate on a 5-point scale how willing they would be to receive mental health treatment ("Not Willing at All" to "Very Willing") via traditional approaches (e.g. face-to-face counseling) and a variety of technology-oriented delivery methods (e.g. website, video teleconferencing, use of VR). Eighty-three percent of participants reported that they were neutral-to-very willing to use some form of technology as part of their behavioral healthcare, with 58% reporting some willingness to use a VR treatment program. Seventy-one percent of SMs were equally or more willing to use some form of technological treatment than solely talking to a therapist in a traditional setting. Most interesting is that 20% of SMs who stated they were not willing to seek traditional psychotherapy rated their willingness to use a VR-based treatment as neutral to very willing. One possible interpretation of this finding is that a subgroup of this sample of SMs with a significant disinterest in traditional mental health treatment would be willing to pursue treatment with a VR-based approach. It is also possible that these findings generalize to SMs who have disengaged from or terminated traditional treatment.

3.3 Preliminary Results from an Open Clinical Trial using Virtual Iraq at the NMCSD

The *Virtual Iraq* system built from this user-centered design process is currently being tested in an open clinical trial with PTSD-diagnosed active duty SMs at NMCSD and Camp Pendleton. The Office of Naval Research funded the initial system development of *Virtual Iraq* along with this initial trial to evaluate the feasibility of using VRET with active duty participants. The participants were SMs who recently redeployed from Iraq and who had engaged in previous PTSD treatments (e.g., group counseling, SSRIs, etc.) without benefit. The standard treatment protocol consisted of 2X weekly, 90-120 minute sessions over five weeks that also included physiological monitoring (HR, GSR and respiration) as part of the data collection. However, in this open clinical trial, elements of the protocol were occasionally modified (i.e., adjusting the number and timing of sessions) to meet patients' needs and thus these data represent an uncontrolled feasibility trial. The VRET exposure exercises followed the principles of graded behavioral exposure and the pace was individualized and patient-driven. The first VRET session consisted of a clinical interview that identified the index trauma, provided psychoeducation on trauma and PTSD, and instruction on a deep breathing technique for general stress management purposes. The second session provided instruction on the use of Subjective Units of Distress (SUDS), the rationale for prolonged exposure (PE), including imaginal exposure and in-vivo exposure. The participants also engaged in their first experience of imaginal exposure of the index trauma and the in-vivo hierarchy exposure list was constructed with the first item assigned as homework. Session three introduced the rationale for VRET and the participant experienced the VR environment without recounting the index trauma narrative for approximately 25 minutes with no provocative trigger stimuli introduced. The purpose of not recounting the index trauma was to allow the participant to navigate Virtual Iraq in an exploratory manner and to function as a "bridge session" from imaginal alone to imaginal exposure combined with virtual reality. Sessions four through ten focused on the participant engaging in the VR while recounting the trauma narrative. Generally, when participants were putting on the HMD, they were instructed that they would be asked to recount their trauma in the first person, as if it were happening again with as much attention to sensory detail as they could provide. Using clinical judgment, the therapist might prompt the patient with questions about their experience or provide encouraging remarks as deemed necessary to facilitate the recounting of the trauma narrative. The treatment included homework, such as requesting the participant to listen to the audiotape of their exposure narrative from the most recent session. Listening to the audiotape several times over a week functioned as continual exposure for processing the index trauma to further enhance the probability for habituation to occur. In-vivo hierarchy exposure items were assigned in a sequential fashion, starting with the lowest rated SUD item. A new item was assigned once the participant demonstrated approximately a 50% reduction of SUDs ratings on the previous item. Self-report measures were obtained at baseline and prior to sessions 3,5,7,9,10 and one week and three months post-treatment to assess in-treatment and follow-up symptom status. The measures used were the PTSD Checklist-Military Version (PCL-M) (Blanchard et al., 1996), Beck Anxiety Inventory (BAI) (Beck et al., 1988) and Patient Health Questionnaire-Depression (PHQ-9) (Kroenke & Spitzer, 2002).

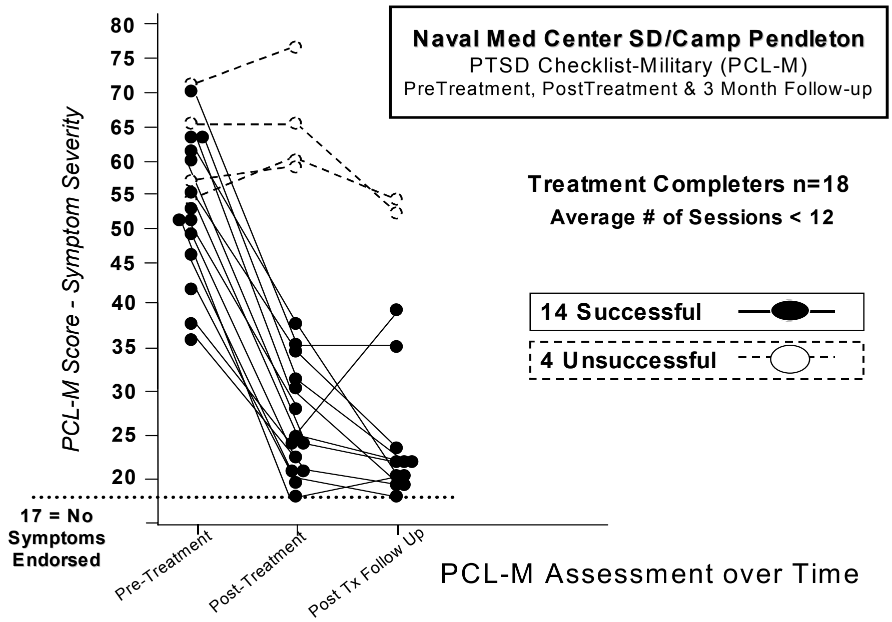

Figure 4. *Individual PCL-M Results from first 18 VRET Treatment Completers.*

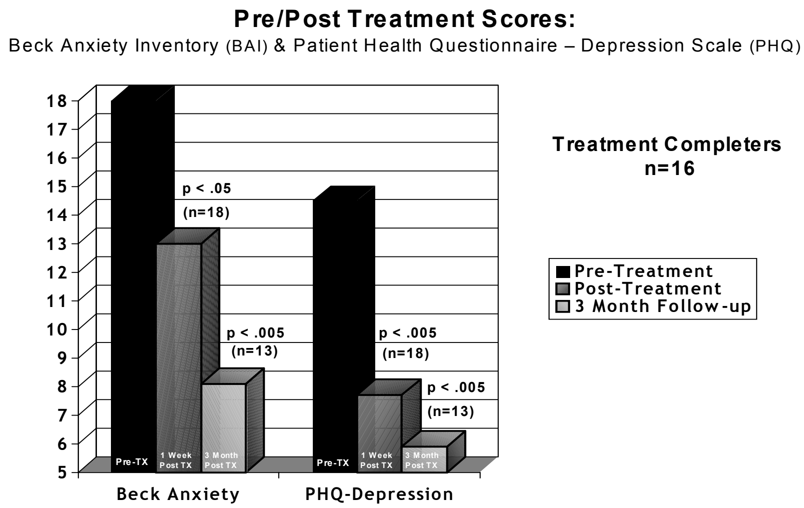

Figure 5. *Mean Group BAI and PHQ-D Results from first 18 VRET Treatment Completers.*

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As of the submission date for this paper, initial analyses of our first 18 treatment completers (17 male, 1 female, Mean Age=28, Age Range: 21-51) have indicated positive clinical outcomes. For this sample, mean pre/post PCL-M scores decreased in a statistical and clinically meaningful fashion; Mean (standard deviation) values went from 54.7 (10.4) to 33.2 (18.6). Paired pre/post t-test analysis showed these differences to be significant ($t=5.28$, $df=17$, $p < .001$). Correcting for the PCL-M no-symptom baseline of 17 indicated a greater than 50% decrease in symptoms and 14 of the 18 completers no longer met DSM criteria for PTSD at post-treatment. Five participants in this group with PTSD diagnoses had pretreatment baseline scores below the conservative cutoff value of 50 (prescores= 49, 46, 42, 36, 38) and reported decreased values at post-treatment (postscores= 23, 19, 22, 22, 24, respectively). Individual participant scores at baseline, post-treatment and 3-month follow-up (for those available at this date) are in Figure 4. For this same group, mean Beck Anxiety Inventory scores significantly decreased 33% from 19.6 (9.5) to 13 (13.6), ($t=2.4$, $df=17$, $p < .05$) and mean PHQ-9 (depression) scores decreased 49% from 14.5 (4.5) to 7.7 (6.2), ($t=3.2$, $df=17$, $p < 0.005$) (see Figure 5). The average number of sessions for this sample was just under 12. Also, two of the successful treatment completers had docume-nted mild and moderate traumatic brain injuries, which suggests that this form of exposure can be useful (and beneficial) for this population. In spite of these initial positive results for treatment completers, challenges existed with dropouts from this active duty sample. Seven participants who were assessed and approved for the study failed to appear at the first session, six attended the first session and dropped out prior to formal commencement of VRET at session four, and seven dropped out at various points following session four. While some of these active duty participants left due to transfers and other reasons beyond their control, these dropout numbers are concerning and we intend to examine all data gathered from this subset of the total sample to search for discriminating factors. This open trial will continue until we have 20 treatment completers and at that point we intend to examine the dropout issue and to analyze the physiological data that we have logged throughout the course of this trial.

4. CONCLUSIONS

Results from such uncontrolled trials and case reports are difficult to generalize from and we are cautious not to make excessive claims based on these early results. At the current time we are encouraged by these early successes and we continue to gather feedback from the patients regarding the therapy and the Virtual Iraq environment in order to continue our iterative system development process. We continue to update the *Virtual Iraq* system with added functionality that has its design "roots" from feedback acquired from these initial patients and the clinicians who have used the system thus far. We are using these initial results to develop, explore and test hypotheses as to how we can improve treatment and also determine what patient characteristics may predict who will benefit from VRET and who may be best served by other approaches.

The current clinical treatment research program with the *Virtual Iraq* application is also providing important data needed to determine the feasibility of expanding the range of applications that can be created from this initial research and development program. In the course of the ongoing evolution of this system, our design approach has always focused on the creation of a VR system/tool that could address *both* clinical and scientific PTSD research questions in a more comprehensive fashion. In this regard, we envision the *Virtual Iraq* application to have value as a tool to:

- study the feasibility of assessing soldiers in advance of deployment to predict those that might have a higher likelihood of developing PTSD or other mental health difficulties based on physiological reactivity (and other measures) to a series of virtual combat engagements.
- deliver "stress inoculation" training to better prepare military personnel for what might occur in real combat environments.
- study the effectiveness of using VR as an assessment tool that is administered immediately upon redeployment in order to determine who may be "at risk" for developing full-blown PTSD after an incubation period. Psychophysiological reactivity could figure well as a marker variable for this project and a prospective longitudinal study is needed in this area. This is particularly important for maximizing the probability that a soldier at risk would be directed into appropriate treatment or programming before being sent on a 2nd or 3rd deployment.
- study the impact of multiple traumatic events on the course of PTSD as may be relevant for the reintegration of military personnel into civilian settings following multiple deployments.
- study the differences between National Guard, reservist personnel, Army/Marine/Air Force standing military SMs and veterans in terms of their susceptibility for developing PTSD and if variations in the course of treatment would be required. This is also relevant for the study of PTSD treatment response

differences due to age, gender, education, family support, and previous exposure to trauma (as in the case of a reservist who served in emergency services as a civilian in the police or fire dept. where exposure to traumatic events commonly occurs).

- evolve understanding of the neuroscience of PTSD via the use of brain imaging protocols (e.g., fMRI, Diffusion Tensor Imaging), traditional physiological measurement (e.g., EEG, EKG, GSR, etc.) and other forms of body-based responses (e.g., eyeblink, startle response and other motor behaviors) by leveraging the high controllability of stimulus events that is available with the *Virtual Iraq* application.
- study the treatment efficacy of *Virtual Iraq* across a range of standard therapeutic issues (i.e., what rate of exposure is needed to optimally treat PTSD).
- study the interaction between the use of VR exposure in combination with a host of pharmacological treatment strategies (e.g., D-cycloserine). Randomized controlled trials comparing VRET alone and VRET+D-cycloserine are currently in progress at Emory University and at Weill Cornell Medical College after successful results were reported with VRET+D-cycloserine for treating fear of heights.
- expand the functionality of our existing system based on the results of the ongoing and future research. This will involve refining the system in terms of the breadth of scenarios/trigger events, the stimulus content and the level of Artificial Intelligence of virtual human characters that "inhabit" the system.

One of the more foreboding findings in the Hoge et al., (2004) report, was the observation that among Iraq/Afghanistan War veterans, *"...those whose responses were positive for a mental disorder, only 23 to 40 percent sought mental health care. Those whose responses were positive for a mental disorder were twice as likely as those whose responses were negative to report concern about possible stigmatization and other barriers to seeking mental health care*." (p. 13). While military training methodology has better prepared soldiers for combat in recent years, such hesitancy to seek treatment for difficulties that emerge upon return from combat, especially by those who may need it most, suggests an area of military mental healthcare that is in need of attention. To address this concern, a VR system for PTSD treatment could serve as a component within a reconceptualized approach to how treatment is accessed by SMs and veterans returning from combat. Perhaps VR exposure could be embedded within the context of "post-combat reintegration training" whereby the perceived stigma of seeking treatment could be lessened as the soldier would be simply involved in this "training" in similar fashion to other designated duties upon redeployment stateside. VRET therapy may also offer an additional attraction and promote treatment seeking by certain demographic groups in need of care. The current generation of young military personnel, having grown up with digital gaming technology, may actually be more attracted to and comfortable with participation in VRET as an alternative to what is viewed as traditional "talk therapy" (even though such talk therapy typically occurs in the course of a multi-component CBT approach for this disorder).

Finally, one of the guiding principles in our development work concerns how novel Virtual Reality systems can extend the skills of a well-trained clinician. VR exposure therapy approaches are not intended to be automated treatment protocols that are administered in a "self-help" format. The presentation of such emotionally evocative VR combat-related scenarios, while providing treatment options not possible until recently, will most likely produce therapeutic benefits when administered within the context of appropriate care via a thoughtful professional appreciation of the complexity and impact of this disorder.

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Session II

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Virtual reality methodology for eliciting knowledge about public transport accessibility for people with acquired brain injury

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ABSTRACT

The aim of this study was to investigate if and how a virtual reality-based methodology can be used to elicit knowledge about public transport accessibility for people with acquired brain injury (ABI). Four subjects with ABI and four occupational therapists made a bus trip in an immersive virtual environment. Their knowledge about public transport accessibility was elicited using the think aloud technique. All subjects managed to handle the VR methodology sufficiently well. The two subject groups tended to focus on different aspects of accessibility in public transport systems. The results suggest that a VR-based methodology can be used to elicit a wide spectrum of knowledge about public transport accessibility for people with ABI.

1. INTRODUCTION

The needs and wishes of people with acquired brain injury (ABI) are scarcely considered when planning public transport systems. One reason for this is the lack of suitable design tools; questionnaires, interviews, and focus groups are in general not feasible for this population. A desirable methodology would attempt to elicit knowledge about accessibility by letting people with ABI directly experience the planned public transport system. Virtual reality (VR) technology provides a means for such a methodology since it allows the creation and visualisation of three-dimensional environments with which people can interact. The use of VR to elicit the knowledge of people with cognitive disabilities is a largely unexplored area of research. The only known effort so far, with the exception of our own research, is a collaborative project between the University of Teesside and Durham University in the UK that studies the use of VR to allow people with dementia to test outdoor environment designs. The findings suggest that a VR-based methodology can be useful in the evaluation of outdoor environments and for identifying improvements for people with dementia (Blackman et al, 2007). There is good reason to believe that a VR-based methodology could also be used to elicit the knowledge of professionals who are experts on people with ABI. According to Schön (1983), most professionals know more than they can put into words. For example, an occupational therapist might find it difficult to share his/her knowledge and experiences of the accessibility problems of people with ABI through interviews or focus groups. To directly experience the environment and reflect over its accessibility through recollections of past cases might be a better approach. The purpose of the present study was to investigate if and how a VR-based methodology can be used to elicit knowledge about public transport accessibility for people with ABI. More precisely, the following three research questions were addressed:

RQ1: How does such a VR methodology work for people with ABI?

RQ2: How does such a VR methodology work for occupational therapists?

RQ3: What type of knowledge can be elicited with such a VR methodology?

2. METHOD

2.1 Material

The VR system was composed of three screens (each 3 x 2.25 metres) on which the virtual environment was projected (Figure 1). The virtual environment contained some built environment and two bus lines, bus 1 and bus 11, which went in loops. The subjects performed actions in the virtual environment by verbally

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describing them to the person controlling the VR system and/or pointing with a laser pointer. We chose this interaction method since we wanted to make it as easy as possible for the subjects to perform actions in the virtual environment. The development and an initial evaluation of the VR methodology, in which seven people with stroke participated, are described in Wallergård et al (2008).

Figure 1. *The VR system.*

2.2 Subjects

Four people with ABI and four occupational therapists were selected for participation. The subjects with ABI were selected to have their most salient cognitive impairment in language, attention, memory or spatial ability, and little or none in the other cognitive domains (Table 1). The assumption behind this sampling was that these four cognitive domains have the greatest effect on a person's ability to handle the VR methodology. Furthermore, the cognitive impairment of the subject was not to be so severe that he/she could not travel independently by bus. The following three inclusion criteria also applied to the subjects with ABI:

- At least six months since brain injury to make sure that the subject had some experience of how his/her impairment affected daily living.
- Did not easily become car sick due to the risk for simulator sickness.
- Had adequate vision to watch TV.

The subjects were assessed with *Cognistat*, a standardised instrument for screening cognitive function (Lezak et al, 2004).

Table 1. *Subjects with ABI.*

Subject	Sex	Age	Type of brain injury	Most salient cognitive impairment	Misc.	Bus experience
1	F	38	Stroke	Language	Broca's aphasia and speech dyspraxia.	One time/week
2	M	41	Stroke	Spatial ability	–	Two times/week
3	F	58	TBI	Attention	Moderately impaired vision.	Three times/month
4	M	44	TBI	Memory	–	Five times/week

The four occupational therapists had baccalaureate degrees in occupational therapy (Table 2). Our inclusion criteria specified more than three years experience of working with people with ABI. They had little or no experience of interactive 3D simulations.

Table 2. *Occupational therapists.*

Subject	Sex	Age	Experience working with people with ABI (years)	Computer experience
5	F	29	3.5	Quite good. Played computer games as child.
6	F	30	5.5	Internet and mail.
7	F	27	3.5	Internet and word processing.
8	F	28	6.0	Internet and word processing.

2.3 Procedure

First, the subject's informed consent was obtained. Then he/she was asked to sit on a chair in front of the VR system while the test leader took his place at a table with a joystick and a keyboard. The subject was then informed about the scenario:

> *You want to take the bus from your flat to a café. You will do this by taking bus 11 to the city centre and then transfer to bus 1. You will get off bus 1 at the bus stop Smörlyckan where you will find the café. The date and time is the same as in the real world. You have a wallet with a bus card inside.*

The subjects were also told that they could perform actions in the virtual environment by telling the test leader what they wanted to do and/or pointing with the laser pointer at the projector screens. The subjects were then given a memory note with written information about which buses to take so that their performance would be independent of their ability to remember the instructions. The experiment consisted of three phases that were different for the two subject groups (Figure 2):

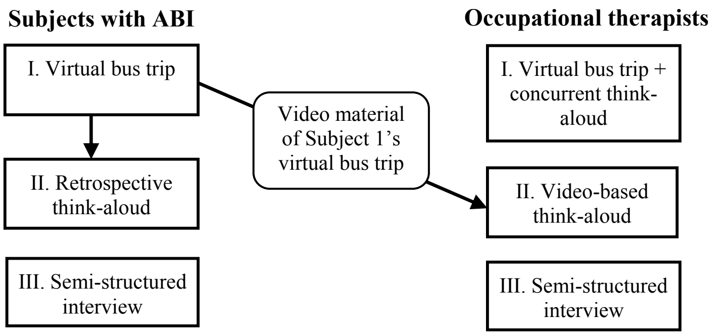

Figure 2. *The procedure.*

2.3.1 The virtual bus trip (Phase I). The occupational therapists were requested to think aloud about aspects related to accessibility for people with ABI while making the bus trip. This is called concurrent think-aloud and is extensively used in for example usability testing (Ericsson & Simon, 1993). The occupational therapists were told that they could ask the test leader to pause the simulation. This made all the events in the virtual environment come to a halt but the subject still could move around in and interact with it. The purpose of the pause function was to provide the subjects with time to reflect over something without being disturbed. The subjects with ABI were not asked to think aloud while performing the bus trip since concurrent think-aloud can interfere with task performance (Russo et al, 1989; van den Haak et al, 2003). We reasoned that this effect might be exacerbated in people with impaired cognitive ability.

2.3.2 The subsequent think-aloud session (Phase II). Immediately after phase I, the subjects with ABI were asked to think aloud about what they were thinking and feeling during the virtual bus trip while watching the recorded video material thereof. This is called retrospective think-aloud and has the advantage of not interfering with task performance since the verbalisation occurs afterwards. The four occupational therapists were shown the video material from the bus trip of Subject 1 who was judged to have the greatest difficulties to use the VR methodology and they were asked to once again think aloud about public transport accessibility for people with ABI. We reasoned that this would encourage the occupational therapists to reflect on aspects not addressed during their own virtual bus trips.

2.3.3 The semi-structured interview (Phase III). The experiment was concluded with a semi-structured interview.

Approval for the study was obtained from Lund University's ethics committee.

3. RESULTS

3.1 Research question 1: How does the VR methodology work for people with ABI?

In general, all four subjects with ABI managed to communicate their intentions well enough to complete the virtual bus trip. There were problems, however, especially for Subject 1 who had difficulties verbalising what she wished to do. On several occasions, it was difficult for the test leader to understand what she wanted.

However, on all these occasions the test leader was able to discover her intentions by posing a question, as illustrated by the following excerpt when she was searching for the outer door of the virtual flat:

S1: *There [points at the hallway]. The door [points at the toilet door]. Open [points at its door handle].*
S1: *Again [points at the outer door].*
TL: *Again..?*
S1: *Eh… Close the door [points at the toilet door].*
TL: *You close the door.*
S1: *Now [points at the outer door].*
TL: *You want to try that door instead?*
S1: *Yes. Open.*

The excerpt also demonstrates her main strategy throughout the whole experiment, namely pointing with the laser pointer in combination with one or several keywords. Another strategy she used on several occasions was to make gestures, especially when she was inserting the bus card in the bus card reader. Despite her problems to provide clear descriptions, she commented during the interview that she thought it was easy to communicate what she wanted to do. Subject 3 also communicated her intentions in a less than optimal manner. On many occasions throughout the bus trip, she just pointed at the projection screens without saying anything. She also seemed to believe that she could interact directly with virtual objects with the laser pointer and she confirmed this during the interview. Despite this, the communication between Subject 3 and the test leader worked sufficiently well. A strategy she used on several occasions during the virtual bus trip was to use words like 'here', 'there' and 'this' while at the same time pointing with the laser pointer. During the interview she revealed that she found the interaction method to be very good, since the user can show with the laser pointer if he/she has problems explaining his/her intentions. Subjects 2 and 4 used very clear verbal descriptions in combination with pointing with the laser pointer throughout the experiment. Just like Subject 3 they combined words like 'here', 'there' and 'this' with pointing with the laser pointer. During the interview, Subject 2 described the method for interacting with the virtual environment as 'not so difficult'. Subject 4 commented that the interaction method worked very well.

Subjects 3 and 4 described the virtual environment as very realistic and mentioned that the experience actually was like riding on a real bus. However, Subject 4 added that the virtual environment did not feel very real in the beginning but gradually became more realistic. One thing he experienced as unrealistic was the movements of the buses, which he perceived as very slow. On several occasions, Subject 1 also made the same observation. She mentioned that the virtual environment was empty and that there were no sounds of other people on the bus. Subject 2 commented that the virtual environment felt a bit weird and unusual and that the real world is easier. Later he developed this line of reasoning:

S2: *But then again… if I had done this a couple of times I probably would have gotten into it. The first time it is a bit… Well, one doesn't think in the right way, I guess.*
TL: *Do you mean that if you had the opportunity to get used to the virtual environment it would have become more like reality?*
S2: *Oh yes. It sure would.*

The interview revealed that all four subjects with ABI had a positive opinion of the VR methodology and seemed to believe that it can be useful.

3.2 Research question 2: How does the VR methodology work for occupational therapists?

In general, the four occupational therapists handled the VR methodology well. They all managed to think aloud in a satisfactory manner during the virtual bus trip and the video-based think-aloud session. Subjects 6 and 8 were completely self-motivated whereas the other two each needed questions from the test leader to think aloud on a couple of occasions. Subject 6 commented during the interview that thinking aloud while watching the video of Subject 1 was like analysing or assessing a patient. Subject 8 expressed that she was unsure whether she was making relevant comments. There were differences in how the occupational therapists used the pause function. Subject 5 paused the virtual bus trip just once whereas Subjects 6 and 7 paused it sporadically. Subject 8 used the pause function almost every time she had something to say. In general, the occupational therapists revealed a positive attitude to the VR methodology. Nevertheless, they also pointed out issues that might be problematic. For example, Subject 5 mentioned that being in the virtual environment felt like being inside a computer game and also made her feel 'a bit clueless'. She pointed out several times that her movements in the virtual environment were slow, which she perceived as unrealistic. Subject 6 also touched upon the issue of the virtual environment being different from the real world during the interview:

S6: *It's a different thing compared to taking the bus in the real world, I would say. One has to think more every moment and since I am not quite sure what will happen, I have to think more about each step. […] It's a little bit like doing something for the first time, because when I do it in the real world I might not think so much about (it)… Then I do it spontaneously but now I have to think about each step…*
TL: *Would it be an advantage or a disadvantage that you have to think more about what you're doing?*
S6: *In this context it's an advantage. […] I have some patient cases that I have experienced which I try to think about in every step and connect to this.*

Moreover, Subjects 5 and 6 commented during the virtual bus trip and the interview that the virtual environment was calm and quiet and empty of people and cars.

3.3 Research question 3: What type of knowledge can be elicited with the VR methodology?

All in all, the subjects with ABI made 79 utterances about public transport accessibility. The following excerpt from Subject 4's retrospective think-aloud session is a good example of what the think-aloud was like. Subject 4 is watching the video material of himself reading the bus stop sign and the timetable while waiting for bus 11:

S4: *I need to be in control so I have to… I don't trust myself and therefore… I see now that I am looking at the memory note a lot, you know. What is written on the note should be up there on the sign. It should match…*
TL: *Are you comparing, so to speak?*
S4: *That's right, I am comparing. […] Then I looked at the timetable there, to check that it's correct…where I am…since I don't know…I am not familiar with this place. I don't know the order in which the Stortorget bus stop comes. And then I check the time at which the bus should leave.*

The utterances could be sorted into five types as shown in Table 3.

The language impairment of Subject 1 made it difficult for her to provide detailed descriptions during the retrospective think-aloud session. It became more like a conversation with the test leader as demonstrated by the excerpt below, which is about her trying to understand if bus 1 was the right bus or not. She seemed to get confused that bus 1 was going in the direction she just came from and that the sign on it was 'Södra Torn' (the end station) and not 'Smörlyckan':

TL: *What were you thinking here?*
S1: *Unsure. The bus… Hmm… Café. Right way [points at the TV screen].*
TL: *Aha. Did you think it was that way? That you should have continued..?*
S1: *Yes.*
TL: *You went the other way. Did this confuse you?*
S1: *Yes. Name. Right.*
TL: *Do you mean the destination sign on the bus? It said 'Södra Torn'. Did this make you unsure?*
S1: *Yes.*

The four occupational therapists made 122 utterances regarding public transport accessibility in total. The following excerpt from Subject 6 is a good example of what the concurrent think-aloud during the virtual bus trip was like. She has just entered the bus and is preparing to pay with her bus card:

S6: *You can stop here. This is a bit of a problem… for many people. If you have spatial problems it's often hard to know the direction in which to insert the card. It should be possible to indicate it somehow. There should be better indications both on the card and on the machine, so you can put it in correctly and don't have to stand there getting nervous and stressed.[…]Everything is so dark. Here it melts into the background [points at the card reader]. I don't know if it's the seat or what, but everything is really black here. It's good with this yellow border here, however, but… I know that inserting the card correctly can be difficult. Mmm… maybe the machine should be another colour to make it stand out.*

The occupational therapists' utterances could be sorted into four types as shown in Table 4.

The utterances concerning 'Accessibility problems' could be further divided in four categories (Table 5):

- Cognitive (e.g. difficulties understanding the timetable)
- Affective (e.g. paying with the bus card is very stressful with people waiting behind you)
- Physical (e.g. difficulties reaching the stop buttons)
- Social (e.g. bus drivers who are rude to individuals with communication problems)

Table 3. *Utterances made by the subjects with ABI.*[1]

Type of utterance	Data type	Subject 1	Subject 2	Subject 3	Subject 4	Total
Accessibility problems (that might occur in public transport)	Bus trip	1	0	1	0	2
	Video	6	5	8	4	23
	Interview	2	4	1	3	10
Suggested improvements (of the public transport system)	Bus trip	0	0	0	0	0
	Video	1	0	0	0	1
	Interview	1	0	0	1	2
Positive aspects (of the public transport system)	Bus trip	0	0	0	0	0
	Video	0	2	1	1	4
	Interview	0	0	0	0	0
Strategies (used by the subject in public transport systems)	Bus trip	0	0	1	0	1
	Video	0	5	2	5	12
	Interview	0	0	0	0	0
The subject's own performance (when making the virtual bus trip)	Bus trip	0	1	0	0	1
	Video	6	5	2	6	19
	Interview	0	2	0	2	4

[1] The subjects with ABI made some utterances also during the interview.

Table 4. *Utterances made by the occupational therapists.*

Type of utterance	Data type	Subject 5	Subject 6	Subject 7	Subject 8	Total
Accessibility problems (that might occur in public transport)	Bus trip	6	11	3	14	34
	Video	5	5	5	6	21
Suggested improvements (of the public transport system)	Bus trip	0	9	0	15	24
	Video	0	2	0	8	10
Positive aspects (of the public transport system)	Bus trip	0	1	1	4	6
	Video	0	1	0	0	1
The performance of Subject 1 (when making the virtual bus trip)	Bus trip	N/A	N/A	N/A	N/A	N/A
	Video	11	2	9	4	26

Table 5. *The four categories of accessibility problem utterances.*[2]

Accessibility problem category	Number of utterances ABI	OT
Cognitive	26	46
Affective	8	10
Physical	4	1
Social	0	1

[2] Some utterances could be grouped to more than one category.

In general, the occupational therapists believed that there were differences between the knowledge coming from the virtual bus trip that they took and the knowledge from the video-based think-aloud session. Subjects 5, 6 and 7 described the knowledge from the video-based think-aloud session as 'another type of understanding', 'more specific to the patient's problems' and as giving 'a completely different perspective'. Moreover, Subject 6 described the matter in the following manner:

S6: *I can only sit here and brainstorm about how I think people would experience it but when I see a patient in the (virtual) environment I am able to directly reflect on it… How was she thinking at that moment? Why* *did it end up like that? That can give you additional insight. You can also see people's reactions. […] That is something I cannot imagine when taking the bus trip by myself.*

All four occupational therapists believed there were differences between the knowledge elicited from themselves and that elicited from the subjects with ABI. Subject 5, for example, commented as follows:

S5: *When observing a patient who does this, you immediately gain empirical knowledge on how it might be, whereas when I comment on things, I generalise on the basis of my expert knowledge.*

Subjects 6 and 7 commented during the interview that people with ABI often have problems expressing what the problem really is. Subject 6 described the issue as follows:

S6: *They generally have great difficulties describing what the problem actually is. They say it's difficult, or they say something really basic like 'I can't see' or 'I can't hear'. On the other hand, if you have some knowledge about cognitive problems you can sort out the cause of the problem, and perhaps you also know how to fix it.*

4. CONCLUSIONS

The results of the present study, in combination with those from our previous research (Wallergård et al, 2008), suggest that a VR-based methodology can be used to elicit a wide spectrum of knowledge about public transport accessibility for people with acquired brain injury (ABI). The subjects with ABI as well as the occupational therapists managed to handle the VR methodology sufficiently well. Nevertheless, some problems were noted. Most importantly, Subject 1 had difficulties due to her language difficulties. Even so, she found strategies that helped her to communicate what she wanted to do. Her use of keywords in combination with pointing with the laser pointer shows that this interaction method can be a suitable for people with language impairments. Subjects 2, 3 and 4 used a strategy similar to Subject 1's keyword strategy: They combined words like 'here', 'there' and 'this' with pointing at objects or places in the virtual environment. This strategy was also observed in our pilot study: Five of the seven stroke subjects applied it (Wallergård et al, 2008). This enabled them to make simpler verbal descriptions and still communicate their intentions clearly, lowering the extraneous cognitive load the VR interface inevitably places on the user. A minimised extraneous cognitive load is very important for the validity of the VR methodology since it otherwise might be difficult to determine if the problems the user experiences are due to the VR technology or an accessibility problem in the portrayed environment. Moreover, the subjects seemed to perceive the virtual bus trip as a somewhat unrealistic experience that demanded more thinking. Nevertheless, it seemed to be convincing enough to trigger their knowledge and experiences. Furthermore, as pointed out by Subject 6, being forced to think each step over in the virtual environment could also be an advantage for this particular application.

In general, it went well for the occupational therapists to think aloud while making the virtual bus trip, which suggests that this is a feasible means of eliciting their knowledge. Nevertheless, Subjects 5 and 7 occasionally needed to be encouraged by the test leader to do so and Subject 8 was not sure if her comments were relevant. One way to remedy these problems would be to allow the occupational therapist to become acquainted with the think-aloud protocol before the actual bus trip starts. They could perform a number of daily activities while thinking aloud about accessibility for people with ABI. Thereafter they would receive feedback so there would be no doubt that they are making relevant comments during the bus trip. Even if Subject 8 was the only subject who used the possibility to pause the VR simulation in a structured manner, we believe that it should be part of the VR methodology. It seemed to facilitate her think-aloud process as she got more time to reflect over the events in the virtual environment.

As expected, the major part of the subjects' utterances about accessibility problems concerned cognitive issues. However, utterances related to emotional aspects, such as stress and insecurity, were also made. This knowledge may be just as relevant: It is crucial to understand in detail what triggers negative reactions in people with ABI when using public transport. Logan, Dyas and Gladman (2004) found that in a group of stroke patients (n=24), 11 wanted to use transport but had lost their confidence. To focus on affective dimensions when planning a public transport system can be a way to make the traveller feel more relaxed and confident.

More than a fourth of the occupational therapists' utterances were suggested solutions to accessibility problems in public transport. This is a very positive result since it suggests that the VR methodology encourages occupational therapists' ability to analyse how things can be improved. One way to develop the suggested improvements and take them one step closer to actual implementation would be to use the knowledge of engineers with expertise in information technology. By letting them directly experience the problems that can occur for people with ABI and elaborate on the suggested solutions from the occupational therapists, they could suggest concrete technical solutions to the public transport planners as illustrated in Figure 3. Since the technology experts are familiar with the possibilities of modern information technology, they would also be able to suggest innovative solutions for long-term improvements. Such solutions could then be evaluated using the VR methodology to see how they work for the end-users and how they can be improved.

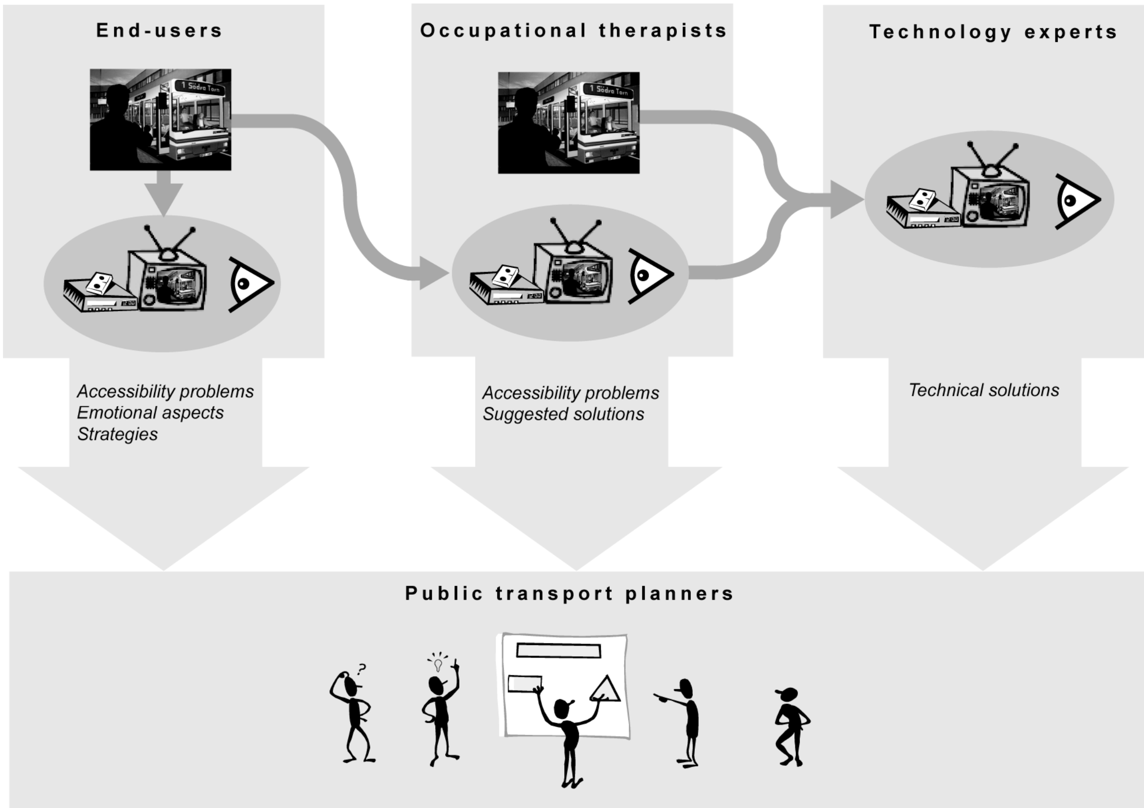

Figure 3. *Applying the VR methodology in a public transport planning process.*

The utterances regarding strategies were unique for the subjects with ABI and constitute knowledge likely to be very useful in a planning process. Sheehan, Burton and Mitchell (2006) investigated outdoor wayfinding in people with dementia by studying 13 dementia subjects on outdoor walks. The authors concluded that knowledge about the wayfinding strategies of this population is important when planning the built environment. In the context of public transport planning, supporting already existing end-user strategies can be a way to minimise the need to re-learn, which probably is particularly important for individuals with impaired memory.

The knowledge elicited from the occupational therapists during the virtual bus trip was somewhat different from the knowledge from the video-based think-aloud session. The virtual bus trip utterances regarding accessibility problems tended to rely more on generalisations based on different consequences of cognitive impairment. The video-based think-aloud utterances, instead, tended to be more focused on Subject 1. Moreover, the occupational therapists themselves believed that the video-based think-aloud session provided another type of understanding. Taken together, this suggests that both methods provide unique knowledge and should be part of the VR methodology in order to cover as many aspects as possible of public transport accessibility for people with ABI.

The language problems of Subject 1 bring up questions concerning the validity of her utterances. There were some things she wanted to communicate but never managed to explain clearly enough. Individuals with language problems may be one of the groups that will have the most difficulties contributing their knowledge through the VR methodology. Even so, they are a big population whose needs must be considered in public transport planning, especially since there is good reason to believe that many of them could use a public transport system designed to compensate for their language impairments. Even if it can be difficult to elicit detailed knowledge from this population, their holistic experience of a virtual public transport system is likely to be useful in a planning situation. Perhaps one of the most valuable contributions from the end-users

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has to do with empathy. In a real planning situation the public transport planners would be able to observe the problems, anxiety or stress of people with ABI when making virtual bus trips (Figure 3). To see this with their own eyes would make them more aware of the consequences of a badly planned public transport system and also more willing to consider the needs of individuals with cognitive impairments in the planning process.

In summary, the results of this study suggest that a VR-based methodology can be used to elicit a wide spectrum of knowledge about public transport accessibility for people with ABI. Our next step will be to try it out in a real planning process related to public transport by involving end-users, occupational therapists, technology experts and of course public transport planners.

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Exploration of computer games in rehabilitation for brain damage

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ABSTRACT

Cognitive and physical deficits are consequences of stroke/traumatic brain injuries (TBI). Without rehabilitation activity problems persist i.e. limitations to handle personal care, the work situation, and recreational activities. The aim of this study is to test an application of Virtual Reality (VR) technology with 3D computer games as an occupational therapy assessment/treatment method in rehabilitation for patients with cognitive and physical deficits. We also wanted to investigate if playing computer games resulted in improved cognitive function. An easy-to-use semi-immersive workbench with haptic game selection menu was located at an activity centre. The training activities were 3D computer games. Every time an activity was run, data about the hand movements were collected and analyzed. Quantitative variables were time (s) to perform the test, average velocity (m/s) and, tremor or uncertainty in movements HPR). Executive functioning was examined by utilizing Trial Making Test. The intervention involved five patients. Results provide evidence to support the use of 3D computer games in cognitive rehabilitation. As an implementation tool within the occupational therapy area, this technology seems to be well adapted to the technological and economical development of society in Sweden.

1. INTRODUCTION

Individuals who survive a severe stroke/ TBI (traumatic brain injury) face long-term problems with impairments, which create deficits in motor control and cognitive function. Without rehabilitation activity problems persist i.e. limitations to handle personal care, the work situation, and recreational activities. Occupational therapy aims to enable clients to engage in self-directed daily occupations in the areas of self-care/self-maintenance, school, work and leisure or play (American Occupational Therapy Association 1994). Thus, OT aims to promote recovery through purposeful activity; it encourages relearning through practice of functional tasks, with tasks gradually being made more difficult (Trombly *et al.* 2002). Relearning daily life activities often comprises intensive training, feedback and training in an environment that motivates the patient to train (Carr *et al.* 1996). If the focus is on these three aspects in rehabilitation, the design of activities should be attractive. When engaging people in occupation, the volition experience is an important factor. The term volition has been used to conceptualize motivation (Kielhofner *et al.* 1995). Kielhofner (1997) defines volition as "a system of dispositions and self-knowledge that predisposes and enables people to anticipate, choose, experience, and interpret occupational behavior". Volition is concerned with what one holds important and finds enjoyable and satisfying. In order for stroke survivors to benefit from play or leisure participation, OTs must aim to find occupations that bring forth volition and discover ways to stimulate motivation (Chern *et al.* 1996). To create attractive activities it is important to understand the patient's subjective experience of the activity. Interventions that are productive, pleasurable and distracting can be efficient. Absorbing and interesting activities have a valuable effect on mood, health and recovery (Pierce 2001). The fact that an activity is pleasurable is important for motivating the patient. A well thought out mixture of the above mentioned aspects has the greatest probability for motivating the patient (Pierce 2001).

Employing computer games to enhance training motivation is an opportunity illustrated by the growing interest in the field of Serious Games (www.seriousgames.org). A serious game is a computer-based game with the goal of education and/or training in any form. This stands in contrast to traditional computer games, whose main purpose is to entertain. Serious games include games for learning, games for health and games for policy and social change. The health care sector is showing steadily increasing interest in serious games. Integrating gaming features into virtual environments has been reported to enhance motivation in adults undergoing physical and occupational therapy following a stroke (Jack *et al.* 2001; Kizony *et al.* 2005). According to Rizzo and Kim (2005), designers of rehabilitation tasks can benefit from enhancing motivation by leveraging gaming factors whilst presenting a patient with a repetitive series of cognitive or physical training challenges. Thus game play within an interactive and graphic-rich environment could support increased user engagement and consequently engagement in the rehabilitation process. The aim of this study is to test an application of VR technology with 3D computer games as an occupational assessment/treatment method in rehabilitation for patients with stroke/TBI with cognitive and motor deficits in an open rehabilitation centre.

2. MATERIAL AND METHODS

2.1 Participants

The study was carried out at an open rehabilitation centre in Uddevalla, Sweden. Five participants after stroke/TBI were recruited from that facility (Table 1); all participants were living in the community in their own homes.

Table 1. *Demographics for 5 participants in the study.*

Participants	Sex	Age (Years)	Etiology	Lesion site	Months since accidence
P1	M	60	Stroke	L	25
P2	M	48	TBI	R	68
P3	M	71	Stroke	R	9
P4	F	61	Stroke	R	9
P5	F	48	TBI	R	24

TBI: Traumatic Brain Injury, L: Left, R: Right.

2.2 Design

The intervention used a pre/post design. The intervention consisted of playing 3D-computer games during their rehabilitation period (2 times a week for 45 minutes for four weeks). The VR environment consisted of a semi-immersive workbench (fig. 1). The user observed a 3D image displayed above the tabletop using stereographic shuttered glasses. The user was able to reach into a virtual space and interact with 3-dimensional objects, using a haptic device (Phantom Omni, www.sensable.com). This created the illusion of manipulating virtual objects. A haptic game selection menu was designed, selecting various games with the haptic stylus from a game library (fig. 2).

2.3 Test procedures

2.3.1 Computer-based measurements (kinematics): we administered an upper extremity (UE) test developed in a previous study (Broeren *et al.* 2004; Broeren 2007). The task required the subject to perform reaching movements of the upper extremity (holding the haptic stylus), as dictated by the target placements. The targets appeared one after the other on the screen and disappeared when pointed at. The target placements (in all 32) in the 3D space were apparently random to the patients but were actually set according to a pre-determined kinematic scheme for evaluation purposes. Each assessment was composed of one trial during one session. Hand position data (haptic stylus end-point) were gathered during each trial. The x-, y- and z-coordinates, which were time stamped, gave the basic pattern of hand movement. After completion, the following registrations were examined; time (s) and distance (m). From this avg. velocity (m/s) and HPR (hand-path ratio – the quotient between actual hand trajectory and the straight-line distance between two targets) was calculated. Reference values for time (s), avg. velocity (m/s) and HPR were used from a previous study (Broeren *et al.* 2008).

Figure 1. *Semi-immersive workbench.*

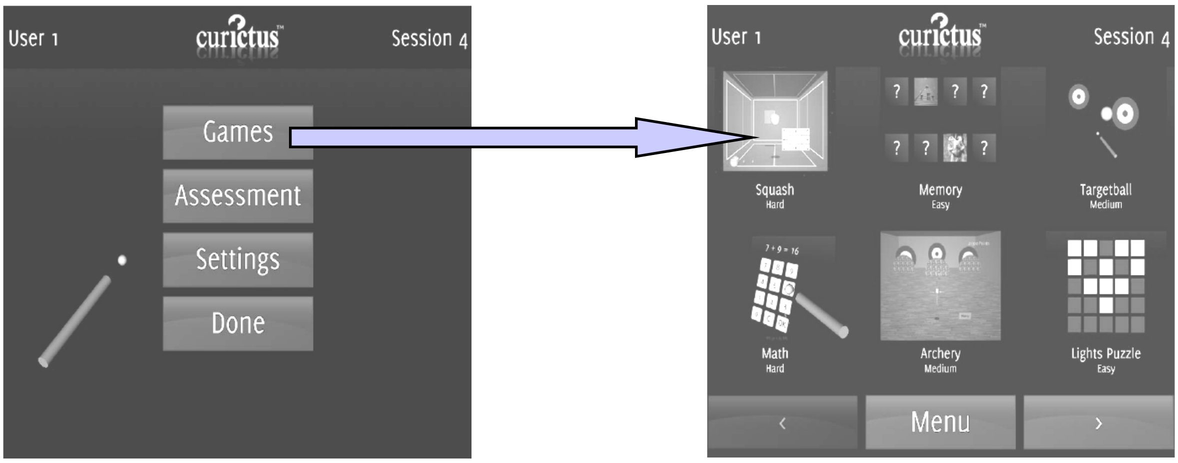

Figure 2. *Curictus user interface and haptic game selection menu.*

2.3.2 Executive function and attention. Trail Making Test, part A and B were used (Spreen and Strauss 1998). 1998). TMT assesses psychomotor speed and attention, and is regarded as a test of executive functioning. Part A requires drawing lines sequentially connecting 25 encircled numbers distributed on a sheet of paper and 25 and part B requires lines sequentially connecting encircled numbers and letters (e.g., 1, A, 2, B, 3, C, etc.). The time (s) taken to complete was used as the overall score.

3. RESULTS

3.1 Computer-based measurements (kinematics)

Time (s) was defined as the overall time to complete the UE test, executing movement to different targets in 3D-space. HPR reflects the coordination of these movements. A comparison between pre/post testing suggests that all participants decreased in the time parameter. An increase in avg. velocity (m/s) was found in four participants, P1, P3, P4 and P5. HPR decreased for P1, P2, P3 and P5. Three participants (P1, P3 and P4), time values were close to the reference values for time (s); 38.3s (SD: 12.5). For avg. velocity (m/s) none the participants came close to the reference value of 0.25 m/s (SD: 0.1). Three participants, P1, P2 and P5, HPR measure were within the range of the reference group value 2.1 (SD: 0.3).

Table 2. *Computer-based measurements for the participants.*

	Time (s)		Avg. Velocity (m/s)		HPR	
Reference values*	38.3s (SD: 12.5)		0.25 m/s (SD: 0.1)		2.1 (SD: 0.3)	
	Pre testing	Post testing	Pre testing	Post testing	Pre testing	Post testing
P1	88,62	54,24	0.12	0.21	2.31	1.88
P2	82,22	64,66	0.11	0.10	3.37	1.66
P3	67,80	54,21	0.17	0.20	2.59	2.51
P4	97,95	53,65	0.14	0.18	2.33	2.62
P5	120,38	67,09	0.14	0.19	3.31	1.99

* Reference values from a previous study (Broeren *et al.* 2008)

3.2 Executive function and attention

The raw scores for all participants are presented in Table 3. Scores achieved by P1, P3 and P5 for TMT A and B no longer differ from the normative sample (Spreen and Strauss 1998), indicating improvement. For P2 improvements were seen in TMT B and for P4 only in TMT A.

Table 3. *Performance time (in seconds) for participants on the Trail Making Trial, part A and B.*

		Pre testing	Post testing
P1	A	60	36*
	B	80	75*
P2	A	34	29
	B	84	52*
P3	A	58	45*
	B	345	180*
P4	A	60	24*
	B	65	45
P5	A	75	24*
	B	140	76*

* Improvements in relation to normative scores (Spreen and Strauss 1998).

4. DISCUSSION AND FUTURE WORK

At present the results of the study are tentative but the general experience of the VR application approach suggests that this intervention seems to be a promising tool in occupational therapy with a wide range of applicability. The limitations of the current study included the small sample size and the lack of other neuropsychological measures. A central component of this rehabilitation system is a library of engaging activities (games) that are simultaneously entertaining for the patient and beneficial for rehabilitation. Since patients have different impairments and abilities, a possibility to customize game play aspects is desirable. Currently, we have about a dozen games, no one fully designed and evaluated. In order to efficiently use computer games to train a particular function, we need to first determine what features a computer game should have to maximally benefit the skill in question. The game library is under construction and more games are to be developed and evaluated. However, game library construction for rehabilitation purposes is still an immature process. Applications should be developed with multidisciplinary collaboration and continuous user-centred input/evaluation methods. A major obstacle for this is the lack of models, methodologies and tools for VR system/content development (Rizzo and Kim 2005).

A brain damage may affect both motor and cognitive functions and the need for effective therapies and innovative rehabilitation is clear. Training with haptic devices has been suggested to enhance rehabilitation. Bardorfer and colleagues developed a method for evaluating the functional studies of the UE in subjects with neurological diseases (Bardorfer *et al.* 2001). The Rutgers group (Jack *et al.* 2001; Boian *et al.* 2002) developed a haptic interface called the "Rutgers Master II" force feedback glove. Conner *et al.* (2002) used an approach to rehabilitation of cognitive deficits following stroke using haptic guided errorless learning with an active force feedback joystick and computer. Baheux and colleagues (2006) developed a 3D haptic virtual reality system to diagnose visuospatial neglect. Kim *et al.* (2004, 2007) designed a VR system to assess and train right hemisphere stroke subjects. This study shows that the subjects made improvements in the kinematic variables measured with the haptic stylus (hand position data). Improvements were noted in time (s), avg. velocity (m/s), except P2, and HPR (except P4). Cognition is generally defined as the individual's ability to obtain and use information in order to adjust to environmental demands. TMT provides information on a number of factors, such as perceptual speed, attention, concentration, flexibility in sequencing, visual scanning, and visuomotor tracking (Tombaugh 2004)(Tombaugh 2004). The performance on the TMT improved and was within the normal range for almost all participants according to published norms (Spreen and Strauss 1998). Cognitive shifting and complex sequencing abilities, as measured by the TMT, appear to be important in determining instrumental activities of daily living (IADLs), regardless of the method used (Cahn-Weiner *et al.* 2002). Cognitive functions are important for the ability of the patient to gain from rehabilitation and to perform compensation. Playing computer games have the potential for therapeutic intervention of cognitive deficits. It can promote sustained attention, self-confidence and motivation of subjects during repetitive task training through multimodal immersive displays and interactive training programmes (Huang *et al.* 2006). The current findings are suggestive of further research in cognitive rehabilitation for the brain damage with this semi-immersive workbench (www.curictus.com).

5. CONCLUSION

It is possible that our results are due merely to an increase in task complexity when increasing level of difficulty in the computer games. Further research is needed to explore this issue. In addition, it is important to explore whether these findings generalize to activities of daily living. As an implementation tool within the occupational therapy area, this technology seems to be well adapted to the technological and economical development of society in Sweden.

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Changes in electroencephalographic spike activity of patients with focal epilepsy through modulation of the sensory motor rhythm in a brain-computer interface

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ABSTRACT

In epilepsy persistence of seizures, despite appropriate pharmacological therapy, motivates referral to surgery of epilepsy, currently the most effective treatment. Because surgery is not indicated for all patients, search for alternative therapies is ongoing. Preliminary data suggests the potential benefit of sensory-motor rhythm modulation on the epileptic activity. However, no controlled studies have been performed. Our study evaluates the benefits of sensory-motor rhythm training to reduce spike activity in Rolandic epilepsy patients with frequent spike activity. Using a Brain-Computer Interface, we obtained a statistically significant modulation of the Mu rhythm and variation of interictal spike activity.

1. INTRODUCTION

Epilepsy is one of the most prevalent neurological diseases and it is among the most common brain disorders worldwide, with no age, racial, social class, and national or geographic boundaries. More than 50 million people in the world today, 85% of whom live in developing countries, have it. The impact of epilepsy ranges from the person with epilepsy to the family and indirectly to the community. The burden of the disease can be due to physical hazards of the unpredictability of the seizures, social exclusion because of negative attitudes of others towards them, and stigma as children with epilepsy may be banned from school, adults may be barred from marriage, and employment is often denied, even when seizures would not compromise patients' work. At least 50% of new cases begin at childhood or adolescence and 70% to 80% of people with epilepsy could lead normal lives if properly treated (WHO, 2005).

Epilepsies are due to an abnormal electrical activation of parts of the brain, which produces not only local dysfunction but can also involve other normal areas and compromise to a variable extent the function of the all brain. Thirty to forty percent of epileptic patients still have seizures even after using several anti-epileptic drugs. Those are considered for surgery, which is an effective procedure, but not available to most patients. A significant number of cases remain that do not have their seizures controlled either by drugs or surgery (WHO, 2005). A number of alternative therapies are then considered which are in general less effective and with a still limited scientific basis. One of these is the modulation of the Mu rhythm by neurofeedback procedures.

Neurofeedback therapies have generated a lot of interest in connection to several pathologies and a therapeutical potential has been recognized in several disabilities such as attention-deficit/hyperactivity disorder (Levesque, 2006; Heinrich, 2004; Strehl, 2006), addictions (Raymond, 2005), cognitive disorders (Vernon, 2003), pseudoseizures (Swingle, 1998) or epilepsy (Kotchoubey, 2001; Monderer 2001; Sterman, 2006).

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Neurotherapy based on neurofeedback is considered to be a brainwave biofeedback, as the participant can consciously know if a desire brainwave pattern is being obtained (Hammond, 2005). In this way and according to Kotchoubey (2001), achieving negative shifts of slow cortical potentials reflect widespread depolarization of apical dendrites of pyramidal neurons and decrease of threshold for paroxysmal activity.

Among those brainwaves, the modulation of the EEG sensory-motor rhythm (SMR) to decrease epileptic activity is a possible option. According to Sterman (2000), changes in SMR activity reflects on average 80% of patients were shown to display significant clinical improvements. The easy implementation of such a method and potential widespread availability deserves a more in depth evaluation of its potential role as an anti-epileptic.

An experimental quantification of the epileptic activity over the sensory-motor brain areas of patients with the syndrome of BRE (benign rolandic epilepsy) has been designed and is undergoing data acquisition. The origin of epileptic spikes in this epileptic syndrome is well known to originate in the rolandic fissure, which is also the most likely area of origin of a physiological EEG rhythm best seen in resting conditions known as Mu rhythm.

The ability to modulate the Mu activity has been well established and the suggestion that such modulation can have an antiepileptic effect (Sterman, 2006) generated interest for its potential therapeutic importance. Nevertheless the antiepileptic effects mentioned in the literature were not based in a sound quantification of EEG spike activity, but instead in seizure frequency reporting. The physiological mechanisms underlying such effects remain poorly characterized. The selection of a group of patients with epileptic activity in the area of maximal Mu activity can provide an important opportunity to better establish the power of Mu rhythm manipulation on the pathological activity and therefore test the previous claim.

Recent studies have reported cognitive impairment in patients with the BRE syndrome which could be related with the interictal spike activity. Such observations suggest that a benefit could be derived from reduction of such activity, independent of the effect in seizure events. Because our patients have very abundant interictal spikes while awake, they are primary candidates to benefit from the reduction of such pathological rhythms.

This on going study will to assess the viability of using a Neurofeedback Brain-Computer Interface (BCI) as an efficient brain SMR training device and evaluate its contribution to modulation of epileptic interictal activity recorded concomitantly.

2. METHOD

2.1 Material

Signal acquisition and BCI presentation were, respectively, obtained and presented on a Pentium IV Laptop computer, with a 2.4Ghz Intel processor and 1Gb RAM, equipped with NuAmps Acquire 4.3.3, a Brain-Computer Interface built around the BCI2000 software package. To acquire patient EEG rhythm, we used a NuAmps 40 channel LT40 Headbox and 12 (Ag/AgCl) scalp electrodes. A PowerPoint slide presentation was developed using two “Search for Waldo” books images. Matlab 6 was used to perform EEG data statistical analysis.

2.2 Participants

Six patients with the syndrome of Benign Rolandic Epilepsy (BRE) and attended in the outpatient clinics of the Pediatric Neurology Department of Hospital Dona Estefânia were included in the study. They were selected from a larger group of patients with the same syndrome by the requirement that they express abundant interictal spike activity in the awakw EEG. No cognitive impairment or motor-sensory abnormalities in the neurological examination were detected.

In BRE patients express high amplitude interictal spikes over the central regions, with a maximum in the electrodes that best pick up the Mu rhythm (C3 and C4 of the 10-20 system). Both types of activity are thought to originate in the sensory-motor areas.

2.3 Procedures

Two conditions were designed in order to modulate the sensory motor rhythm. EEG was recorded on the two conditions to compare the number of epileptic seizures.

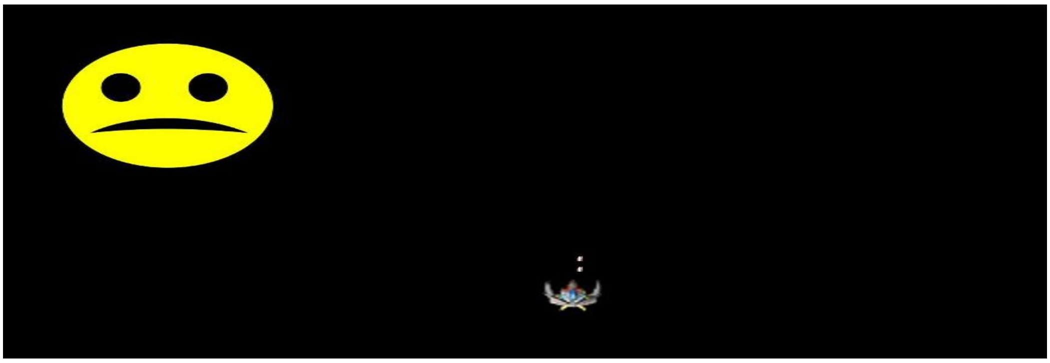

Figure 1. *Space Invaders-type game. Using sensory motor rhythm, the participant must control de cursor (space ship) in order to hit the target (yellow face).*

The first condition (Motor Condition) was assigned as the movement condition. For that, a Space Invaders-type game was created, with random targets in the left or right visual field. The sensory motor rhythm of the central electrodes was used to control the cursor in order to hit the (right or left) target. Both real hand movement and imaginary hand movement were analysed (see Fig. 1).

The second condition (Waldo Condition) was a non-motor condition, in which, several images of "Search for Waldo" were used in order to allow visual search for a target (Waldo) in a slide presentation.

Both conditions were alternatively presented throughout six trials. Each condition consisted on a five minute block so that in both the improvement in sensory-motor rhythm control and the effect of training in epileptic activity could be analysed.

The EEG was continuously recorded at 250Hz rate, using a Hjorth local derivation around the C3 and C4 positions of the 10-20 system of electrode placement. Along with EEG recording, the time of the events and responses from the patient were also registered. Signal was acquired using a 70Hz low pass filter, 1Hz high pass filter and 50Hz Notch. Ground electrode was attached to AFz position and FCz was used as reference.

Several measures of interest are derived from the EEG recording such as the power in the Mu band, amplitude of desynchronization and number of interictal spikes.

The Motor Condition (MC) allowed to create two Mu classes: high and low Mu classes. On the high Mu class the ipsilateral movement electrode activity (C3 for left movement and C4 for right movement) was analysed. The analyses of the contralateral movement electrode activity enabled the creation of the low Mu class.

The Waldo Condition (WC), not involving a motor task, allowed to create a baseline Mu class.

In order to compare these three different Mu classes, in the MC Mu classes, a 3 second-long epochs from the EEG recording were extracted when the visual target was hit. Both C3 ad C4 activity were, also, recorded and classified as a decreased or increased Mu classes, for each hemisphere separately. For the baseline Mu class, 3 second-long consecutive epochs were extracted from the EEG recording while the patient visually "searched for Waldo".

Using the bootstrap method, a time-frequencies coherence plot, with a significant level of 0,01, were produced for each relevant electrode channel. This analysis aimed at comparing pre and post stimuli onset spectral changes.

Epileptic spikes were, also, counted in every Mu class.

3. RESULTS

The experimental setup allowed a reliable modulation of the Mu spectral band. Through the Motor Condition (MC), participants were asked to continuously open and close their target side hand until the target was hit by the cursor. Since the contralateral electrode activity was analysed, a low Mu class was expected to be found due to SMR (sensory motor rhythm) desynchronization.

The Event Related Spectral Plot (ERSP) (Makeig, 1992) demonstrates a Mu band (10-12Hz) reduction around -3dB when the contralateral electrode activity was analysed (Fig. 2). When compared with baseline, the bootstrap technique showed significant spectral changes after 750 ms stimuli presentation. As seen in Fig.

1, about 750ms after stimuli onset, in this case a target appearance on the left side of the screen, there was a desynchronisation only noticed in this band pattern.

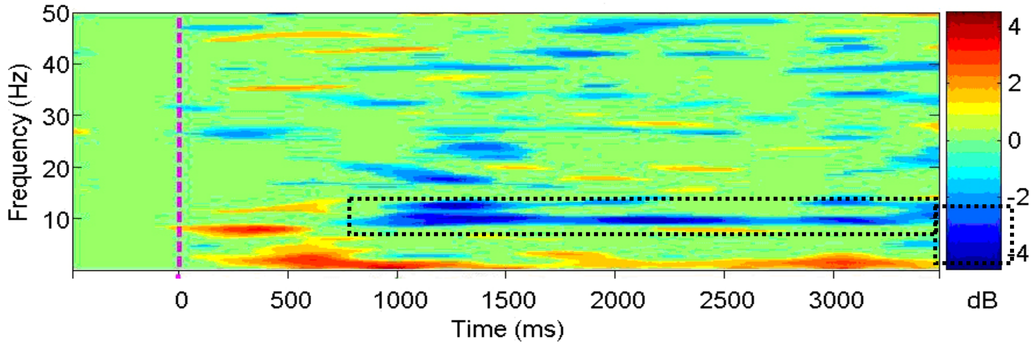

Figure 2. *ERSP plot of significant reduction in the Mu band at contralateral electrode C4 by movement of the left hand.*

Also on the Motor Condition, similar modulation of the Mu spectral band is noticed when the participant is asked not to move his target side hand, but only to imagine the movement. Imaginary hand movement also showed a desynchronisation in the 10-12Hz band, from 500ms after stimulus onset (see Fig. 3). A low Mu class was also found.

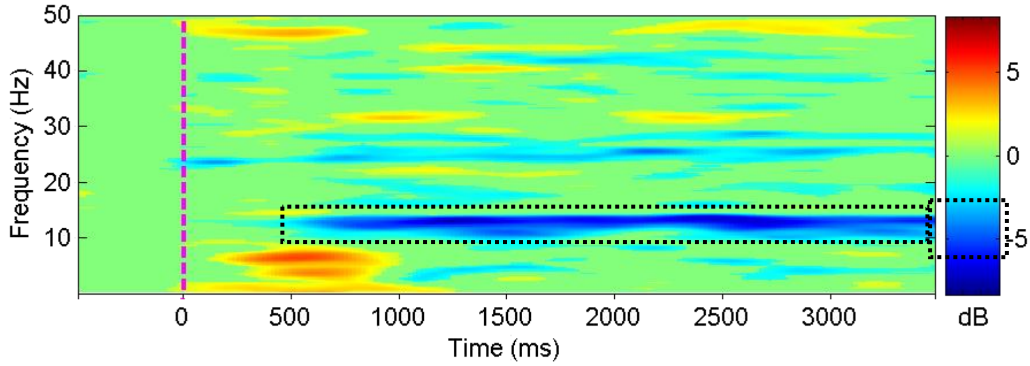

Figure 3. *ERSP plot of significant reduction in the Mu band at contralateral electrode C4 by imagination of left hand movement.*

On the other hand, when the ipsilateral electrode activity is analysed, the ERSP demonstrates changes in opposite directions, over the sensory-motor area (see Fig. 4). In this case, an increase of Mu spectral band is noticed at 10-12Hz.

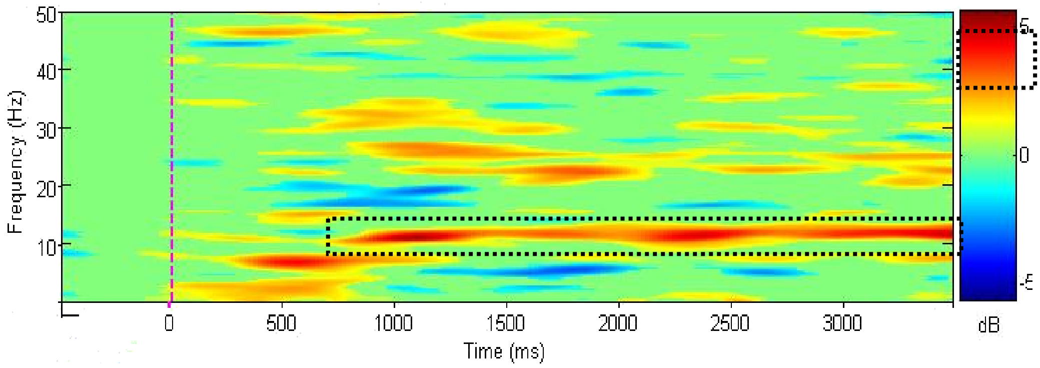

Figure 4. *ERSP plot of significant increase in the Mu band at ipsilateral electrode C3 caused by movement of the left hand.*

Epileptic spikes in benign rolandic epilepsy (BRE) are easily recognized (Fig. 5) and of much higher amplitude than the background rhythms.

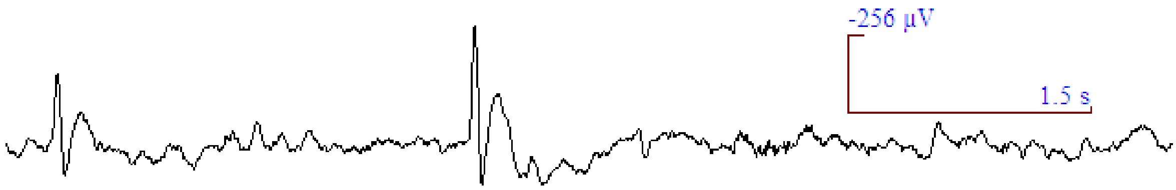

Figure 5. *Examples of epileptic spikes at electrode C3, demonstrating the typical morphology.*

Quantification of the spike activity throughout the sessions in each class of Mu rhythm will provide a means to perform statistical evaluation of the changes both across classes and in the same class through the training process.

4. DISCUSSION

The present study points towards a consistent way to modulate sensory-motor rhythm (SMR) and quantify such changes in order to compare three different Mu rhythm classes. Also, the obtained results showed that no real movements are need as in imaginary movement protocol, significant Mu rhythm changes were obtained.

At a 0-50Hz spectral band analysis, only the 10-12Hz band as statistical significant changes through-out the designed protocol. Therefore, other brain waves influence may be exclude since there are no statistically significant changes at Delta frequency band (0.5-4Hz), Theta (4-8Hz), and Beta frequency (14-30Hz). Also Alpha waves (8-14Hz) are excluded since there are only statistically significant changes after the stimuli onset.

Furthermore, the experimental task has not been contaminated by electromiographic activity artefacts, since no statistically significant changes have been found at high spectral band (above 30Hz). In that way, quantification of spike activity can be strongly associated with Mu rhythm modulation.

The designed protocol also produced different Mu classes that can be compared. Has expected, when movement was required or imagined, a significant Mu desynchronization was obtained in the contralateral electrode electrical.

A significant modulation of SMR was also obtained when the ipsilateral electrode electrical activity was analysed. In fact, the results showed an increased SMR using both real and imaginary movements.

The condition where the participant has to visually search for a target and non movement was required, allowed a base line Mu rhythm comparison, has to analyse a possible placebo effect provoked by sustainable attention.

Training effect was also analysed in order to evaluate if a growing number of sessions provoked a better Mu rhythm control, translated to a better space-invaders game results. Motivation for consistent training to modulate SMR is required. A space-invader like game proved to be a good neurofeedback method, since it seems to be considered a game and not a therapeutic session for these age group participants.

5. CONCLUSIONS

An experimental test of the anti-epileptic effect of sensory-motor rhythm modulation is undergoing, using a BCI optimized for use in a group of young patients with benign rolandic epilepsy and frequent interictal epileptic activity in the EEG. Preliminary analysis of the data suggests that the BCI produced consistent power changes of the sensory motor rhythm and a reliable quantification of the epileptic activity throughout the training process.

Although the expenses associated with de EEG acquisition and needing well trained and experienced technicians are somehow disadvantages of this neurofeedback technique, any advance in alternative epilepsy therapy beside anti-epileptic drugs and surgery, is considered a major breakthrough. In that way, it seems relevant to assess the effect of this technique.

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Effects of different virtual reality environments on experimental pain threshold in individuals with pain following stroke

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ABSTRACT

The objectives of this study were to determine whether different virtual reality environments (VR) had a differential effect on pain threshold (PT) in stroke patients with pain, and whether the patient's level of interest in the VR influenced PT. Ten stroke individuals with pain participated. PT to hot and cold stimuli was determined using Quantitative sensory testing within four different VEs; Hot, Cold, Neutral and no VR. After the VR exposure, subjects rated each VR condition based on their engagement. The results suggest that VR is more effective than no VR and all VR conditions were more engaging than no VR.

1. INTRODUCTION

Stroke is an injury to the part of the central nervous system due to either blockage in or bleeding from an artery that supplies blood to the brain, which causes destruction of a portion of the brain and can lead to loss of muscular control, weakening or loss of sensation or consciousness, dizziness, slurred speech, or other symptom. According to the World Health Organization 15 million people around the world suffer a stroke each year, with five million of those episodes resulting in death and a further five million people left with a permanent disability. Stroke is also the third leading cause of death and the leading cause of disability in high-income countries, such as United States (Swierzewski, 2007). Approximately 780,000 strokes, occur in the United States each year (The Stroke Association, 2008), and the Heart and Stroke Foundation of Canada (2003) has estimated that 40,000–50,000 new episodes of stroke occur in Canada annually.

Pain is a common problem after stroke. Approximately 8% of stroke individuals develop central post-stroke pain (Teasell, 2006). Central post stroke pain is a neuropathic pain syndrome. Most commonly pain occurs within the first 6 months (Bowsher, 2001). The pain has been described as burning, aching, or pricking in nature often accompanied by abnormal sensation in the affected body part such as the face, arm, leg, and trunk. It's usually constant, with a tendency to increase in intensity over time, and differs from other forms of musculoskeletal pain that commonly occur in stroke survivors. Movement, emotional stress, changes in temperature, or other unrelated stimuli may intensify the symptoms. This chronic pain can decrease quality of life, physical function and reduce the ability to concentrate. Chronic pain often leads to depression, and loss of self esteem.

Virtual reality (VR) has been used as a treatment for pain reduction. VR can provide a means of attracting attention to a specific virtual environment or alternatively distracting attention from a painful experience. Since an individuals' attentional capacity is limited, and a distracting technique requires a great deal of the person's attentional resources, this leaves little attentional capacity available for processing painful stimuli (McCaul& Malott, 1984). Attentional resources within different sensory systems act independently so that an activity that involves one sensory modality may not deplete the attentional resources in another (Wickens, 2002). However, pain tends to demand attention. In a series of studies, Hoffman has shown that patients with severe burns using VR have reported large reductions in worst pain, pain unpleasantness, and time spent thinking about procedural pain (Hoffman, 2000, 2001, 2004c). The more engaging and interactive the VR environment is, the more effective is the pain reduction. Overall, the more engaged and distracted patients are, the less they will feel their pain.

Sensory loss, different temperature and blood flow asymmetries between stroke and non- stroke arms are well known clinical problems after stroke. Spinothalamic functions (cold, warmth, pinprick) are most commonly impacted, albeit the impact is characterized by individual variability. As noted earlier, sensory

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abnormalities have been reported in patients post-stroke. For example, skin temperature is usually lower in the contralesional side in patients with stroke, thus sensation of cold on this side are probably influenced by this baseline temperature and thus account for side to side differences (Naver, 1995). It is believed that cold VR environments may reduce pain perception from warm stimuli, while warm environments may reduce pain perception from cold stimuli. Muhlberger (2007) tested young healthy females but found no difference in the type of virtual environment used for distraction (cold or warm) and no interaction with type of pain stimulus provided (warm or cold), and both environments reduced pain perception equally.

The use of immersive VR for post stroke chronic pain has not been previously tested. In addition, it is not clear whether different VRs have a differential effect on pain thresholds, and whether this effect is related to the interesting and engaging characteristic of the VR. This is an important question given that pain is known to be aggravated by heat and cold in (real) environments. The primary objective of this study was to determine whether different virtual environments had a differential effect on experimental pain threshold in stroke patients with moderate to severe persistent post-stroke pain. A secondary objective was to determine whether the patient's level of engagement or interest in the virtual environment influenced pain threshold. We hypothesized that all virtual environments would improve pain threshold compared to the control condition (no VR). We hypothesized that there would be a differential effect of virtual environments on experimental pain threshold based on their interesting and engaging characteristics.

2. METHOD

This study was part of a larger study, designed to determine the effects of different virtual reality environments, and type of stimulus on clinical and experimental pain perception and walking performance in thirty six individuals with stroke, with pain (n=12) and without pain (n=12) in comparison to an age and gender matched healthy cohort (n=12). The current paper is focused on the subjects with stroke and pain.

2.1 *Participants*

A convenience sample of 12 stroke patients with central post-stroke pain (> 2 on a 0 - 10 Numerical Rating Scale) in their upper limb were recruited for this part of study (see table 1). The study procedures were explained to all subjects and an informed consent was signed prior to participation.

Table 1. *Subjects Characteristics (n=12)*

Patients (Stroke & pain)	Age (years)	Gender	Stroke arm	Pain intensity (VAS)[1]	Pain affect (VAS)[1]	Mood (VAS)[1]	MPQ (PPI)[2]	MPQ (PRI)[3]	Years after stroke
Summary data	X± sd 61±7.2	M (n):7 F(n) :5	R (n):7 L (n):5	3.45 ± 1.4*	4.02 ± 1.9*	5.81± 1.5*	2.58 ± .9*	9.3 ± 3.6*	4.08 ± 2.5*

Gender (M: male, F: female)
Stroke arm (R: right, L: left)
[1]VAS: Visual Analog Scale: (0-10)
[2]MPQ: (PPI): McGill Pain Questionnaire (Present Pain Intensity): 0-5
[3]MPQ (PRI): McGill Pain Questionnaire (Pain Rating Index): 0-20 words
* X± SD (mean ± standard deviation)

2.2 *Materials and Equipment*

2.2.1 Quantitative Sensory Testing. QST was done using the method of limits standard test protocol and the NeuroSensory Analyzer Model TSA-II (MEDOC Ltd., Ramat Yishai, Israel) on the painful and contralateral, pain-free forearm in counterbalanced order to assess pain perception to thermal hot and cold stimuli. The TSA-II uses a 30mmX30mm thermode which was placed on the skin of the patients' forearm. Thermal stimuli were delivered by 15 brief (700ms) taps of stimuli via the thermode. Rate of temperature changes were between 0.3 ºC/ sec and 4.0 ºC/ sec. Temperatures between 36 - 47°C were used for hot stimuli and 30 ºC with a rate decrease of 1º C/sec and an automatic safety lower limit of 4.5ºC for the cold stimuli. In the methods of limits, stimuli (hot or cold) increased in intensity to a specific temperature for less than 1 second and then immediately returned to neutral temperature, in preparation for the next stimulus. Six clusters of stimuli were given, with up to six stimuli in each cluster, so a mean was taken in order to derive the pain threshold. Interval between stimuli started from stimulus end to onset of next stimulus which lasted 6 seconds.

Figure 1. *Quantitative Sensory Testing device showing contact thermode (http://www.medoc-web.com).*

Figure 2. *Experimental set up. Note position of contact thermode for QST under forearm, computer mouse controls temperature changes.*

2.2.2 Virtual Reality Environments. The VR computer was equipped with the ultra-high end NVIDIA Quadro FX 4500 graphics card (512 MB of high-speed GDDR3memory). Each VE was presented through a head mounted display (HMD) (Kaiser Optical Systems, Ann Arbor, MI, USA). An ICUBE head-tracking system allowed for looking in any direction and at different parts of the virtual environments. The VE conditions (Figure 3) were randomly presented. They were as follows: 1) "Snow World" (cold) which has snowy mountain canyon scenes (Hoffman, 2004b), 2) Dante's Canyon (hot) is a modification of "Snow World. It has hot volcanic scenes, 3) Neutral is comprised of alternating white pillars on a black background (Powell, 2006), and 4) No VE.

(A) *(B)* *(C)*

Figure 3. *Virtual environments used for experiment: (A) Snow World; (B) Dante's Canyon world; (C) Neutral VE (alternating white pillars on a black background).*

2.3 Measures

2.3.1 Pain Threshold. During each VR condition, three hot stimuli and three cold stimuli were delivered via thermode on the participant's arm. Stimuli (hot or cold) gradually increased or decreased in temperature. After receiving the hot or cold stimulus, participants clicked the mouse as soon as the feeling changed from hot to just painfully hot or from cold to just painfully cold. By clicking the mouse, the thermode temperature immediately returned to neutral temperature and the pain threshold was recorded. The procedure was repeated six times on the patient's arm area (three hot and three cold stimuli). The mean pain threshold was calculated and used for analysis.

2.3.2. Engagement. After the VR exposure, subjects rated each VR condition on the basis of 0-100 Numerical Rating Scale of interest and engagement. Zero represented not at all engaging (i.e. boring) and 100 represented extremely engaging.

2.3.3 Mood. Since emotions, such as mood, influence the affective component of pain in chronic pain patients (Fernandez & Milburn 1994; Wade et al 1990), to control the effects of these confounding variables on patients' pain perception subjects were presented to a 10 cm visual analog scales (VAS) anchored with 0 (extremely bad) and 10 (extremely good) with a mid-point of 5 labeled neutral to assess how were the mood of patients prior to the start of the experiment.

2.3.4 Clinical Pain Intensity

After the VR exposure, subjects rated each VR condition on the basis of 0-10 Numerical Rating Scale of pain perception intensity. Zero represented no pain at all and 10 represented worst pain imaginable.

2.4 Procedures

After obtaining information about subject characteristics of demographics, medical and pain history, the study procedures were explained and an informed consent obtained. The experiments took place in a quiet air-conditioned environment in which the ambient temperature was stable and comfortable (22°C). Participants were exposed to each VR in random order and QST was carried out. Each testing of the VR conditions was completed in approximately 3-5 minutes, and subjects were allowed to rest between each condition. Pain threshold judgments were obtained while subjects viewed the VEs, engagement judgments were obtained after each VE exposure.

2.5 Data Analyses

Summary descriptive statistics were computed and compared for all subjects to establish group homogeneity. Data of pain threshold were analyzed with two-way repeated-measures of ANOVA containing the within-subject factors (VR environments and type of stimulus) using SPSS software, version 15 ($p<0.05$) to analyze the significance of the main effect of VR condition and type of stimulus on pain threshold. To analyze the difference of engagement rating among different virtual conditions one way repeated-measures of ANOVA was used and Tukey HSD was used for post hoc analyses as appropriate.

3. RESULTS

Given that several asymmetries in sensory loss and temperature perception (cold, warmth) between stroke and non- stroke arms may exist, data of pain thresholds for the stroke and non-stroke arm of each subject were averaged separately for hot and cold stimuli and for each VR condition.

3.1 Pain Threshold (Stroke arm)

For the stroke arm in patients with stroke and pain, and with a hot stimulus, all VR environments increased pain threshold in comparison to no VR condition ($F_{3,1} = 2.7$, $p<.05$). Dante's canyon (hot condition) was most effective ($F_{3,1} = 9.08$, $p< .05$). In contrast, and with a cold stimulus, no VR environments reduced pain threshold ($F_{3,1} = .6$, $p>.05$). In addition, visual analysis of the graph of each stroke subject with pain showed when the stimulus was 'hot' pain threshold was most stable across all VR conditions, whereas when the stimulus was cold, pain threshold showed less stability.

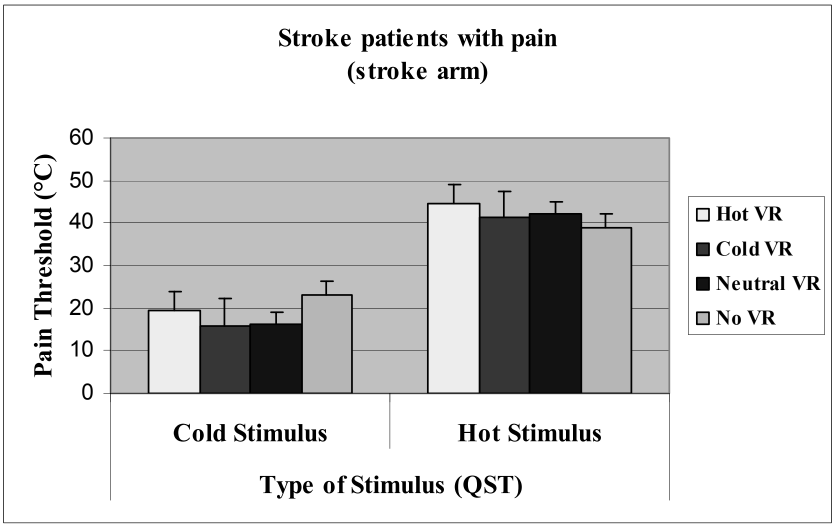

Figure 4. *Mean pain threshold of the cold and hot pain stimuli of the stroke arm of patients with pain during presentation of the virtual worlds.*

3.2 Pain Threshold (Non-stroke arm)

For the non-stroke arm, there was no significant or differential effect of VR condition on pain threshold to hot or cold stimuli ($F_{3,\ 1}$ = 1.73, p> .05) (see table 2). Preliminary analysis showed a trend that Neutral environment resulted in increased pain threshold to both hot and cold stimuli.

Table 2. *Data of pain threshold for the non-stroke arm and stroke arm in stroke patients with pain were averaged separately for hot and cold stimuli and for each VR condition.*

	Stroke with pain (n=12)			
	Non- stroke arm		Stroke arm	
	Stimulus		*Stimulus*	
Virtual Environments	*Cold*	*Hot*	*Cold*	*Hot*
Hot (Dante's canyon)	20.14±4.8	49.02±4.9	19.6±5.4	44.5±5.8
Cold (Snow world)	19.84±7.9	47.36±9.1	15.73±8.1	41.2±8.2
Neutral (White pillars)	24.46±5.2	55.27±5.5	16.4±5.8	42.3±5.02
No VR (Control condition)	23.59±7.3	52.36±8.1	23.2±8.5	39.03±7.2

*Values are mean ± SE

3.3 Engagement

One way repeated-measures of ANOVA was used to analyze engagement ratings across VR conditions. VR engagement was significant across stroke patients with pain ($F_{8,\ 3}$ =17.39, p<0.05). All VRs were more engaging than the control (no VR) condition. Dante's Canyon was the most engaging VR environment, whereas the Neutral condition was least engaging (see table 3). Further, there was a strong and direct correlation between engagement rating of each virtual condition and pain threshold (r = .68; P=0.015).

Table 3. *Descriptive statistics for engagement rating.*

Subjects (n=12)	Engage. Rate **Hot** (0-100)	Engage. Rate **Cold** (0-100)	Engage. Rate **Neutral** (0-100)	Engage. Rate **No VR** (0-100)
Stroke with pain	81.25 ± 5.06	70.83 ± 4.48	66.25 ± 7.72	32.33 ± 8.22

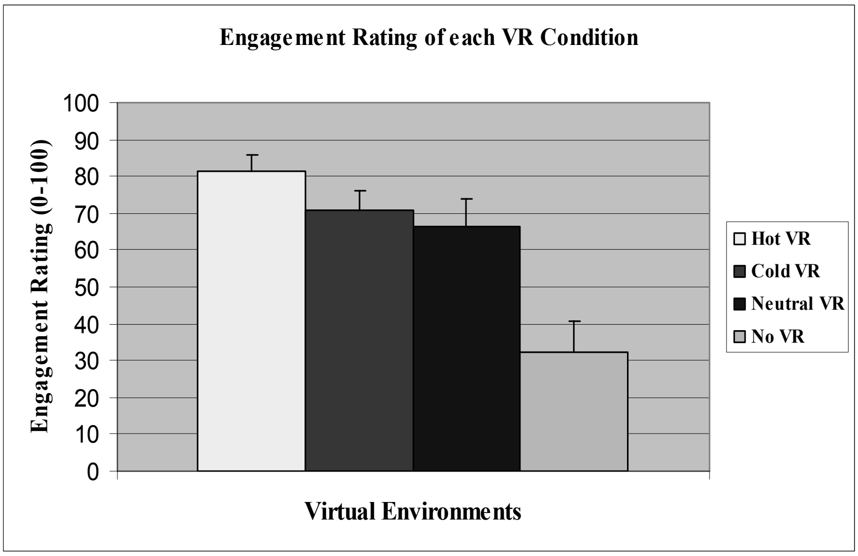

Figure 5. *Mean engagement rating of the stroke patients with pain during presentation of each virtual environment.*

3.4 Clinical Pain Ratings

One way repeated-measures of ANOVA to analyze pain ratings across VR conditions (table 4) showed a significant effect of VR condition ($F_{6,\ 3}$ = 11.67, p< .05,). Among VR environments, both Hot (Dante's Canyon World), and Cold (Snow World) conditions were equally effective ($F_{6,\ 3}$ =12, 13.89, p = 0.01 respectively), whereas Neutral condition was the least effective ($F_{6,\ 3}$ = .25, p= 0.87).

Table 4. *Descriptive statistics for clinical pain rating*

Subjects (n=10)	Clinical pain **Hot VR** (0-10)	Clinical pain **Cold VR** (0-10)	Clinical pain **Neutral VR** (0-10)	Clinical pain **No VR** (0-10)
Stroke with pain	1.75± 1.05	1.75± 1.13	3.83± 2.24	3.75 ± 2.37

3.5 Mood

Correlation between pain threshold and mood was moderate to strong (r range .35 to .75).

4. DISCUSSION

This study compared the relative effectiveness of different VR conditions on pain threshold to thermal (hot and cold) pain stimuli in stroke patients with pain. In line with our hypotheses, the results indicated that all VR conditions increased pain threshold compared to the control condition (no VR). In addition, virtual reality appeared to differentially influence experimental pain threshold to both hot and cold stimuli in patients with stroke and pain. Dante's canyon (Hot environment) was the most effective environment in increasing pain threshold to both hot and cold stimuli when tested on the stroke arm. On the other hand, when tested on the non- stroke arm the Neutral environment was most effective. It is possible that this is due to the oft described mesmerizing effect of the Neutral environment. Certainly, the differential effect between arms is indicative of sensory abnormalities post-stroke. Not surprisingly, all VR conditions were more engaging than the control condition and reduced pain ratings. There was a direct correlation between pain threshold and patients' mood. This is important because it supports the idea that increasing or decreasing mood can modify pain responses in chronic illness, and reflects the importance of using VR in rehabilitation. It is possible that VR may reduce pain in part through its effect on mood. Clearly further investigation is needed.

It is generally acknowledged that cold or warm pressor pain differs from clinical pain in terms of perceived controllability (subjects can stop an experimental test at any time) and in terms of the level of anxiety associated with clinical pain. In the present study, subjects with stroke and with pain reported a significant increase in their experimental pain threshold and a significant decrease in their clinical pain perception during VR exposure, which is consistent with previous reports in subjects using an experimental pain paradigm and acute pain (Hoffman, 2004b, 2004c). It is an important finding because it shows that VR distraction not only increases pain threshold (experimental pain), but also decreases clinical pain.

The results are also generally consistent with those of Muhlberger (2007) who showed the pain perception was reduced in both hot and cold virtual environments compared to the control condition. Muhlberger (2007) also indicated that hot stimuli were always perceived as less painful than cold stimuli, regardless of which VR condition was presented. This is in the line of the results of the present study which showed when the stimulus was hot patients showed a higher pain threshold (less pain perception) in all VR conditions. It is possible that the novelty of the VR environment and helmet as well as the unfamiliar sensations associated with the system may have had an unanticipated effect of initially drawing the patients' attention away from the thermal stimuli.

Not surprisingly, there was a strong and direct correlation between engagement rating and pain threshold which means the more engaged patients were, the less pain they felt. This is in the line of the results of Hoffman et al (2001) that showed highly engaging VR environments are effective in pain reduction. Engagement involves active attention to a stimulus and thus less attentional capacity is available for attending to pain. Active attention (i.e. primary attention due to preference) to a non-pain auditory or visual stimulus (e.g. VR) is known to be a more effective and a longer lasting strategy that passive distraction (i.e. attending to a non-pain stimulus – not out of interest but as an attempt to distract from pain). Thus making VR environments engaging is a potentially important consideration, relative to their use in pain management.

It is generally acknowledged that mood modifies pain in a predictable direction (Walters & Williamson, 1999; Zautra, Burleson, Matt, Roth, & Burrows, 1994). Both experimental and correlational evidence from this study suggests a direct association between mood states and subsequent changes in pain threshold as depressed mood altered pain responses in the expected direction. This is contrary to the results of the study by Edens and Gil (1995) who indicated that negative emotional factors such as depressed mood can increase the severity of chronic in both laboratory and clinical settings. However, this was not conducted in the context of the attentional capacity of VR, nor in the post-stroke pain population.

The small sample size in this study limits the generalizability of VR analgesic efficacy to larger populations of stroke patients. Individual differences and personal characteristics such as degree of ability to concentrate and immerse in VR environment may also mediate the effectiveness of VR. In addition, interactivity of VR environments may influence effectiveness. It is also known that factors such as rate of change of stimulus temperature, reaction time, and method of measurement of psychophysical thresholds significantly influence the measure of the threshold value (Yarnitsky and Ochoa, 1990). The method of limits, as routinely used for threshold determination through the QST, does include reaction time in the measurement, leading to artefactual elevation of thresholds (Fruhstorfer et al. 1976), and sensation of heat-induced pain (Yarnitsky and Ochoa, 1990). Thresholds obtained by this method are therefore bound to be of higher value than those obtained by the method of levels. Although that may influence the magnitude of response it is unlikely to influence the overall results.

5. CONCLUSION

The purpose of this study was to determine whether different virtual environments had a differential effect on experimental pain threshold in stroke patients with moderate to severe persistent post-stroke pain, as well as to determine whether the patient's level of engagement or interest in the virtual environment influenced pain threshold. The main findings were that virtual reality appeared to differentially influence experimental pain threshold to hot and cold stimuli in patients with stroke and pain, with Dante's canyon was considered as the most effective environment. In addition, all VR conditions were more engaging than no VR control. Again Dante's canyon was the most engaging. For perceived pain ratings, both Hot (Dante's Canyon World), and Cold (Snow World) conditions were equally effective. More research is needed on whether people with chronic pain from different conditions respond similarly. Further research is needed to identify the aspects of VR that can enhance effectiveness and increase patients' engagement. Understanding the interaction between individual subject characteristics, (e.g. age, gender, interests, and preferences) and specific VR environments may help tailor treatments more effectively.

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ICDVRAT 2008

Session III

Virtual Reality Methodologies I

Chair: Mattias Wallergård

You are who you know: user authentication by face recognition

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ABSTRACT

In this paper, a novel method of authentication based on user-performed identification of known and unknown faces is described. The target group of the method is the elderly users for which the use of traditional techniques, such as passwords, personal identification numbers (PIN), or biometrics is not without problems. The performance of this method and authentication by PIN has been compared in a two-pass usability study. Our method performed significantly better than PIN. The method is suitable for low-security applications in hospitals and senior houses.

1. INTRODUCTION

One of the consequences of pervasion of the computing equipment is the computerization of household appliances. This enables the producers build devices that provide larger functionality (such as greater level of automation, remote control, or interconnectedness), implement better power-saving strategies, enable better diagnostics, and enable better integration with e-commerce services. Systems, such as serve@home[1] or MS Windows XP Media Center Edition are examples of this trend.

These systems have typically larger requirements on users' ability to use the computing equipment which puts certain user groups into a disadvantage. At least a basic experience with handling the ICT is often necessary to perform even the simplest tasks. This puts novice computer users into a great disadvantage.

There are numerous initiatives addressing these issues. One of them is the project i2home[2]. Its tag line is "the intuitive interaction for everyone with home appliances based on industry standards". One of the target groups of the project is the elderly people (65+).

The elderly users are a user group facing a number of challenges that make the usage of mainstream technology difficult. To this day, many of them have never used any computer-based technologies. We assume this will improve in the future when today's computer-literate middle generation grows older. However, the certain special needs will remain with the elderly people due to their mental skills and eventually physical limitations (vision, hearing, motor abilities).

In our work we have focused on user authentication techniques suitable for elderly people. We consider easy-to-use but robust and secure user authentication as a foundation stone of a further development of complex and feature rich home environments. In the context of i2home, the user is supposed to authenticate before receiving private messages, modify their user profile, etc.

Traditional methods of the user authentication include entering the combination of user name and password and biometric methods such as retinal scans or fingerprint analysis. We believe that for a number of applications in certain medical conditions, the finger or retinal scanning is not possible. We also assume that remembering a password or a Personal Identification Number (PIN) would be difficult for the elderly people.

Nevertheless, there are numerous alternatives available. One of the current topics of research is the use of pictorial information for authentication. Oorschot and Thorpe (2008) present in their article an interesting survey of the topic. Weidenbeck et al (2005) describe a system where the user is required to click on

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predefined parts of the picture that are known only to the user. Tullis et al (2005) and Weinshall et al (2004) describe authentication schemes based on selection of pictures previously assigned to the user from those displayed on the screen. A commercial solution *PassFaces* by Passfaces Corporation is based on identifying previously assigned faces to user's account. To identify a face, the user has to select a picture of the face within a 3×3 matrix of faces and repeat this task until a correct sequence of the faces has been entered.

In this paper, we describe a method similar to *PassFaces* and compare the performance of this method and the traditional user authentication by entering PIN.

2. AUTHENTICATION METHOD

Our method also consists of selection of a face from a matrix of faces. The collection of the faces is provided during an initialization phase by the user. Pictures of all people that the user would safely recognize can be used. However, as opposed to *PassFaces*, our method is based on the selection of the *unknown* face from among the known ones that the user has provided. The unknown face is randomly selected from a pool of unknown pictures. This way we do not require the users to memorize new faces in order to be able to perform the authentication.

The user's authentication is successful in case the user can repeat the task three times in a row. By having the user to select the unknown face out of those presented, we make the authentication harder for a potential intruder who is likely to know only a part of the user's friends.

On the other hand this method is less resistant against attacks of a closely related person who has similar knowledge and sphere of friends and family. Great advantage of this method is that it requires only very little cognitive load from the user as recognition of faces is much more natural operation than recalling the PIN.

Our method is very easy to use even by people with little or no computer skills. The only obstacle represents the interaction with the computer during identification of the unknown face. While using mouse or touchpad is difficult for our target group, using a touch-screen proves to be a very natural way of interaction for the elderly people. This fact was proven in a separate research within the i2home project.

The method could be applied in institutions such as senior houses to separate the private and common areas. We heard many complaints from our test participants about lack of privacy in the senior house they suffer from. Discussions of the same problem could be found in numerous references in literature.

Using privacy regulation model (Bell et al, 2001) for explanation of the meaning of home and primary territories we can apprehend our participants dissatisfaction as insufficient control over intruders entering their territories and invasion of their privacy. On the other hand numerous studies acknowledged that feeling of control over the primary territories is closely associated with greater well-being, positive effects on health and more positive feeling about the environment itself (Gifford 1997).

If such institutions as senior houses aspire to provide home for their inhabitants and not just shelter, features such as defensible markers and clear boundaries between primary (inhabitants' own room) and secondary territories (hall, common room) should be provided.

Our system could serve as a low-security feature for room protection in time when the inhabitant leaves the room. And thus it could significantly enhance inhabitants' feeling of control over their rooms when being not present. Our system can be seen as an alternative solution to the traditional (metal) keys as well as the authentication by PIN. After reviewing the inhabitants as well as the senior house staff, we have found out the following:

- Traditional metal key is not the best solution for our target population because of the risk of its loss. Solving problems with lost keys is an unacceptable work overload for already busy senior house staff.
- Many seniors are using PIN code derived from their life experience. These PINs are related to day of birth of their children, date of marriage etc. Such pins are very vulnerable to social based attacks.
- The staff of the senior house reports difficulties with the learning curve of the seniors, problems related to their memory are often causing they forget the PIN. Consequently the staff has to take appropriate actions to reset the PIN.

As a result of these interviews we think the usage of our system would be of a great benefit for both the inhabitants and the staff.

3. FACE RECOGNITION

Human face recognition has recently received significant attention in association with automated face recognition systems engineering. Cognitive processes underlying face recognition are acknowledged as highly effective. Remarkable is first of all human ability to recognize familiar faces over varying conditions such as varying angle of view, as well as distance, illumination and even degraded depiction (Sinha et al 2006). Understanding such mechanisms is expected to afford useful hints for development of face recognition automated system.

Face developed important role in holding the information about social identity throughout the evolution of human. Ability to identify others immediately and correctly has become crucial for individuals' functioning in diversified society. Face as an instrument for holding extensive social information provides the most important clues for recognizing the others properly.

Research findings of developmental psychology also stress the exceptional role of face recognition among the other higher cognitive processes. Numerous research studies proved the infants' ability to differentiate familiar faces from the other faces as well as visual preference of structures holding traits that are inherent to faces. The most apparent example is the striking ability of neonates to discriminate mother's face from the others (Pascalis et al, 1995). However the effort of developmental researchers is not limited only to infants.

The fact that face recognition abilities stay fairly preserved in old age even when suffering from senile dementia (Ferris et al, 1980) suggests that the face recognition-based authentication seems to be suitable for our target population. Loss of memory as well as many other cognitive abilities observed in aging people does not affect face recognition so significantly, especially when talking about recognizing faces that were learned in preceding stages of life.

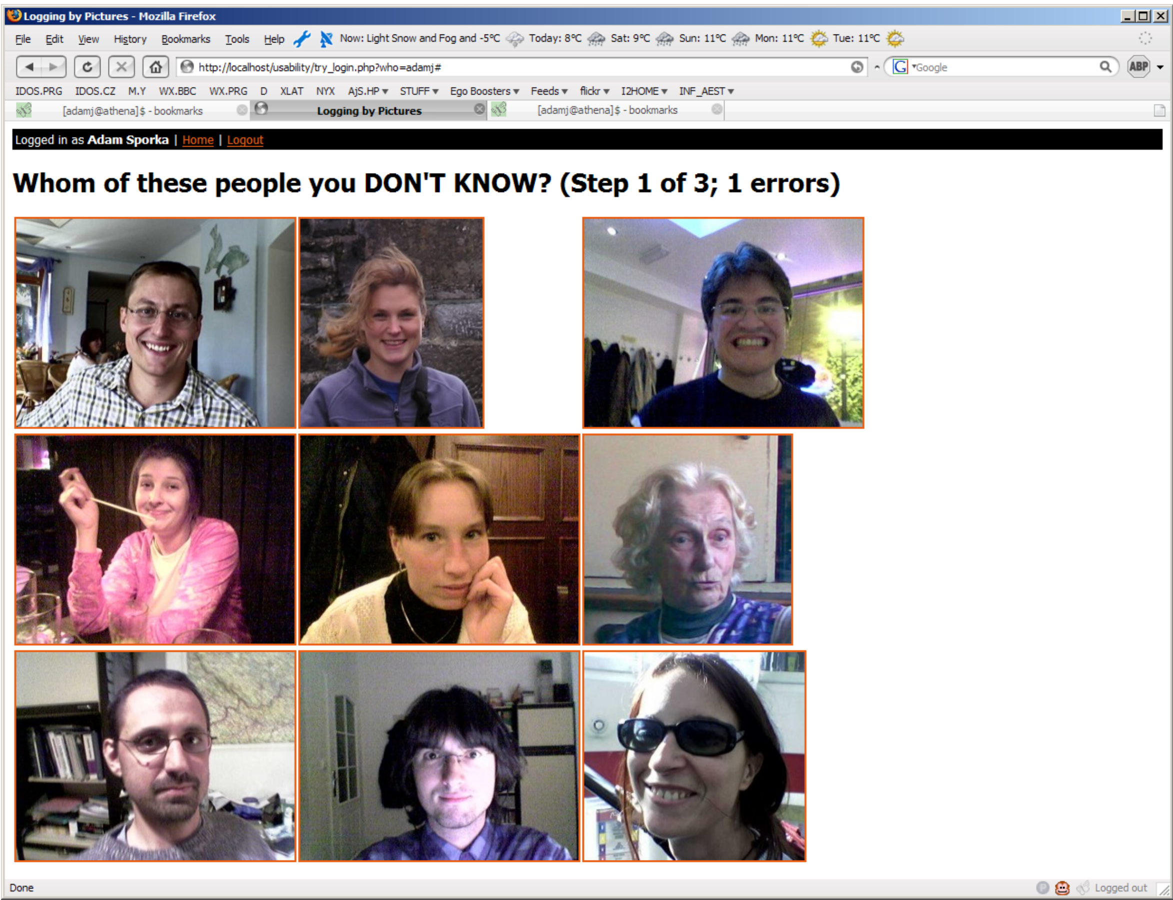

Figure 1. *Screenshot of the authentication prototype tool.*

4. USER STUDY

The goal of this study was to assess the usability of the method that has been developed and to provide a comparison of the method with a commonly used authentication by PIN. The hypothesis of the study was that the log-in by pictures would be more successful than the log-in by PIN, i.e. that there will be more successful authentication attempts by the users when using the log-in by pictures.

4.1 Design

The study was a two-condition within-subject design with repetition.

4.2 Apparatus

A web browser-based prototype application had been written in PHP (Fig. 1.), using Apache HTTP server and MySQL database. The prototype allowed a simple participant management, uploading and automated resizing of the images, and performing the authentication attempts.

During our experiment we instructed the participant to identify the unknown faces by touching a regular LCD screen, the actual selection was made by the experimenter using mouse.

4.3 Participants

There were 9 participants of this study, all females (74 years old, SD 4.2). They all were inhabitants of a senior house located near Prague. The gender of the participants could not be balanced due to the gender profile of the senior house.

4.4 Procedure

The inhabitants of the senior house were invited by the house staff to take part in our study. All people interested in participating gathered in a common room of the senior house a week before the first day of the experiment. The experimenters explained them the goals of the study and have stressed that their participation in the study would be voluntary. In order to help understanding the task, we asked the participants that to imagine they are trying to open a safety vault. Each participant went through two sessions. Each participant was given a small present.

4.4.1 Session 1. A session with each participant consisted of set-up and the test itself. During the set-up phase, each participant signed a consent form. Then, the participant presented the personal collection of photographs to the experimenters who have scanned and uploaded the pictures into the prototype application. The pool of unknown pictures has been generated from the personal collection of one of the experimenters.

At the beginning of the test, the participant was asked to pick and memorize a 4-digit PIN. To approach the real-world conditions, she was advised that certain passwords (repetition of numbers, simple arithmetic sequences, birthdays, etc.) were not acceptable because of their insecurity, as they could be easily guessed. Then she was asked to use our application to attempt a log-in procedure.

The number of attempts needed to complete the log-in successfully was counted. Immediately afterwards, she was asked to enter the PIN. The number of PIN attempts was also counted. The number of attempts was limited to three in both cases, to simulate the behavior of real-world devices, such as cell phones or ATMs, where upon the third failure, the authentication is escalated.

The session took typically between 30 and 45 minutes to complete.

4.4.2 Session 2. 14 days later, a second session has been carried out with each of the participants. Each participant was asked to use our prototype to log in and then she was asked to produce her PIN number. The number of attempts was recorded for both methods with the limit as during the Session 1. The session typically took between 15 and 20 minutes since no set-up was necessary.

The order of the methods tested during the session was fixed due to organizational reasons. However, it could not have affected the results of the experiment: The participants during any of the sessions did not exhibit any symptoms of fatigue or discomfort. On the contrary: After the Session 2, the participants would generally express a disappointment that our visit was too short. Also, our authentication method does not represent any notable cognitive load to the participants and therefore it could not negatively affect the participants' performance in the PIN authentication task.

4.5 Data and discussion

The performance score of the participants is shown in Table 1 for both sessions. On the session 2, the average score of the PIN method was 1.8. Three out of nine users were not able to complete the task successfully. All users were able to finish the task using the picture-based method. Although the number of the participants is relatively small, the difference of the average grades is significant (two-tailed *t*-test, $p < .05$).

Table 1. *Number of attempts taken by the participants.*

		P1	P2	P3	P4	P5	P6	P7	P8	P9	Avg
Session 1	PIN	2	1	1	1	1	1	2	1	1	1.2
	Pict.	2	1	1	3	1	1	1	1	1	1.3
Session 2	PIN	1	1	1	(f) 4	(f) 4	1	1	(f) 4	3	2.3
	Pict.	1	1	1	1	1	1	1	1	1	1.0

Note: (f) denotes a failure to perform the authentication. (Failure is counted as 4 attempts.)

While the users were able to authenticate via both methods on the first session, three users could not pass the PIN on the second session, while all users were still able to perform the picture authentication. The qualitative interviews revealed that our method was generally perceived as "more satisfying", "friendlier", and "easier-to-use".

During the experiment we encountered one participant who had notable problems with memory. Despite of her problems, she performed very well being able to use our authentication method immediately even during the Session 2. We believe that a usability test on people with memory impairment such as Alzheimer's disease should be performed as this method seems to offer benefit over longer period of time than traditional PIN method.

5. CONCLUSION

This paper has reported on a usability test performed on a method of user authentication by means of recognition of human faces on the photographs. The results prove the usability of this method for our target group.

Nine elderly users with no computer skills took part in this study. All of them were able to use the described picture-based method of authentication whereas 3 people were not able to use the authentication by PIN. This study is limited in number of participants. A larger quantitative study must be performed before any possible deployment of our method.

The method shares some benefits and drawbacks with the biometric methods of authentication: The user needs only the life-long knowledge of faces of their family, friends, and colleagues, the authentication procedure is quick and there is no risk of losing the authentication token (password, swipe card, keys…). However, if the potential attacker carries out an extensive study of the user's social background, the security of this method for that user may be ultimately compromised, unless the user later provides previously "unused" faces.

This can happen especially among the members of the family who are likely to know most of the faces on each other's log-in screen as it would be easy for them to guess the unknown person. Therefore, this method is suitable especially for low-security applications in environments shared by multiple people who in general do not know well each other's social history, such as in the hospitals or senior houses. Immediate follow-up will be therefore a statistical study that will examine the level of this threat.

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[1] http://www.servehome.com
[2] http://www.i2home.org

Low-cost optical tracking for immersive collaboration in the CAVE using the Wii Remote

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ABSTRACT

We present a novel way of interacting with an immersive virtual environment which involves inexpensive motion-capture using the Wii Remote®. A software framework is also presented to visualize and share this information across two remote CAVE™-like environments. The resulting applications can be used to assist rehabilitation by sending motion information across remote sites. The application's software and hardware components are scalable enough to be used on desktop computer when home-based rehabilitation is preferred.

1. INTRODUCTION

In the last decade, the use of virtual reality (VR) to assist therapy has received increasing support from the clinical community (Moline, 1997). Advantages provided by virtual reality platforms include ecological validity, that is relevance to real world applications, stimulus consistency, and an easy way to provide motivation by user-friendly and graphically-attractive environments. However at present technological developments limit the interaction between user and environment, and make the process of moving in the environment not comfortable (Rizzo and Kim, 2005). Virtual reality investments also suffer from higher costs of equipment. This type of investment is not appealing to health professionals unless substantial benefits can be projected in return. Thus the recent focus of engineers working in VR has been to scale the technology down so that it is computational lightweight and physically portable, while normal prototyping still takes place on a more expensive scale.

Major applications that currently use VR include, among others, stroke rehabilitation (August et al., 2005; Dobkin, 2004; Merians et al., 2002), and helping locomotion in Parkinson disease (Sveistrup, 2004). In particular, upper-limb stroke therapy has benefitted from neurological research that points to movement exercise as a fundamental tool to recover motion by exploiting neural plasticity (Krakauer, 2005; Nudo and Friel, 1999; Taub et al., 1993; Winstein et al., 1999). This has led to detailed studies of upper limb kinematics in stroke subjects in order to understand motor response after stroke, as well as to design more effective therapies (Levin, 1996; Micera et al., 2005). Virtual reality applications have emerged that target stroke treatment and provide assistance to the therapists during motion exercises. They include assisting movements by robotic mechanisms (Loureiro et al., 2003), capturing hand range of motion (August et al., 2005), speed and finger force using data gloves, as well as providing feedback on exercise performance (Merians et al., 2002). Other applications use a web-based library that is queried by the user during therapy to provide exercises and feedback on performance (Reinkensmeyer et al., 2002). Interactions with the environment happen via a mouse or a low-cost force-feedback joystick or haptic glove (Popescu et al., 2000). These applications provide motivation through the use of interactive environments, puzzles and games. Commercial game platforms (EyeToy™) have also been used to monitor 2D upper limb movements and provide a rehabilitation treatment (Rand et al., 2004). However, in order to capture 3D movements, extended to different upper limb segments, more expensive systems need to be used, including optical or magnetic motion tracking. These technologies come at comparatively high costs (> US$ 20K) for the health service, which in turn means that they are also constrained by the location where they are used.

We present a pilot application where the wireless remote controller Wii Remote® (Wiimote) of the Nintendo Wii® game console is used to perform motion-capture in immersive collaborative virtual reality (VR) environments. The application can also run on non-immersive platforms and desktop computers for a more widespread distribution. The Wiimote provides an inexpensive alternative for 3D optical motion-capture (~ US$ 60 / Wiimote). It integrates, among others, an in-built infrared (IR) camera with on-chip processing, accelerometers and supports Bluetooth® communication. This characteristic makes it suitable to communicate with external hardware that supports Bluetooth, while several open-source libraries are available to capture and process the derived information. The display environments used in the pilot trials presented here are two CAVE™-like systems, which allow perception of 3D stereo graphics from a first-person viewpoint, and have the advantage of an enhanced sense of presence and increased interaction among participants. These were linked via the Internet using a collaborative virtual environment (CVE) software system that runs as a distributed simulation. Alternatively the software can be ported on desktop computers or single screen projection systems without stereo visualization.

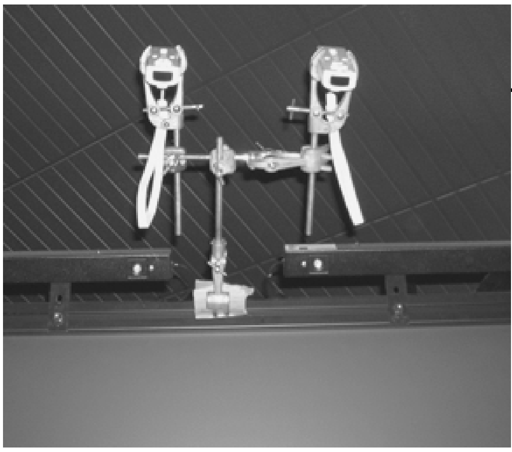
Here, information derived from the Wiimote camera is used to track an IR source, mounted for example on a portable support, and to generate graphics corresponding to the movements of the user. These data are successively shared across the networked CAVE displays via the CVE application.

2. METHODS

When used in the game console the Wiimote tracks the position of two fixed IR sources mounted externally on a device known as 'sensor bar' using the in-built infrared camera. The IR sources appear to the camera as bright spots on a dark background. From these 2D images, the 3D position of the Wiimote is calculated based on the known distance between the 2 fixed IR sources in the sensor bar.

In our applications, the Wiimote was used in the reversed way. Two Wiimotes were mounted on fixed supports inside each CAVE, while the participants moved an IR source. The IR source (wavelength 950 nm) was captured by both Wiimote cameras and this information was communicated to a computer enabled to receive Bluetooth and which run the server software (referred to as wiitrack). The IR source was easily created from an IR LED (IR pen), or alternatively by shining IR light generated via a LED array on a reflective marker attached to the participant's hand. Figure 1 shows the physical mounting of the Wiimotes in one CAVE.

The 3D coordinates of the IR source were calculated locally by each wiitrack application and sent to each local CAVE-rendering application (CVEclient), while the 3D coordinates of the IR source in the remote CAVE were communicated across the 2 sites via relay server application (CVEserver). A scheme of the data flow and software is shown in Figure 1. The system was tested by 2 healthy participants, working at each remote site in a series of accuracy tests and pilot rehabilitation trials.



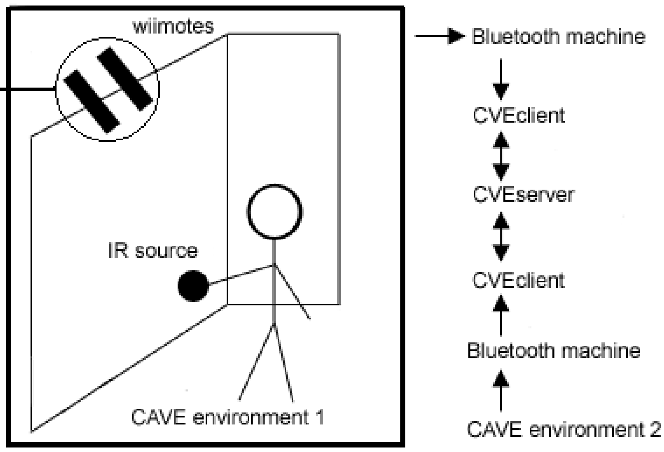


Figure 1. *Left: Physical mounting of the Wiimotes on top of the CAVE front wall and IR pen. Right: Wiimote use in a shared virtual reality environment. CVE: Collaborative Virtual Environment.*

2.1 Wiitrack Server

Each Wiimote has an IR camera with a 1024x768 pixels resolution and approximately 40 degrees field of view. The 2D coordinates of the IR source as seen by each Wiimote camera were read by the wiitrack application using the wiiuse (Laforest, 2008) open-source library. These 2D coordinates were then filtered independently for each Wiimote using a Butterworth filter with a ratio between sampling over cutoff frequency: $f_s/fc = 8$. Sampling rate of each Wiimote camera was was 100 Hz, transmission rate between wiitrack and CVEclient was 30 ms. The three-dimensional position of the IR source was calculated using stereo triangulation with 2 parallel Wiimotes facing the IR source (see Figure 2) as:

$$
\begin{aligned}
X_{actual} &= x_{cleft} \frac{Z_{actual}}{f} \\
Y_{actual} &= y_{cleft} \frac{Z_{actual}}{f} \\
Z_{actual} &= \frac{b \cdot f}{x_{cleft} - x_{cright}}
\end{aligned} \quad . \tag{1}
$$

Where the Z axis is the direction towards which the cameras are pointing, b is the distance between the cameras, f is the focal length, *xcleft* and *xcright* are x IR source coordinates on the left and right view planes respectively.

A graphical user interface (GUI) was written for wiitrack in C++ to take into account parameters such as Wiimotes origin location, rotation and Wiimote camera sensitivity. The latter is adjustable from a level 1 to a maximum of 5 in wiiuse. Averaging the past n positions to calculate the $n^{th}+1$ position was also included as an option, both before and after filtering took place.

The reason for implementing the tracker algorithm in a separate application, rather than within the CVEclient itself, was that the visualisation computer driving the CAVE did not support Bluetooth natively. Therefore, wiitrack had to run on a separate computer and communicate the tracking data via the local area network (LAN) to the CVEclient. However, this server-based tracker solution also allows other applications than the CVEclient to access the tracking data virtually in parallel, e.g. to log a patient's performance for later analysis. Communication between wiitrack server and CVEclient was implemented using the open-source library RakNet (Jenkins_Software, 2008). Another open-source option also available is the VRPN (Taylor II et al., 2001). The network delay for delivering tracking data from the wiitrack server to the CVEclient was typically between 16 to 19 ms.

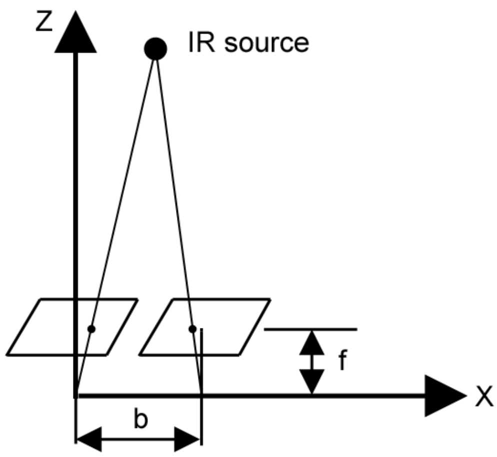


Figure 2. *Stereovision for 2 Wiimotes. The Wiimotes axes are parallel to the Z axis. The 2 parallelograms represent the view planes of the Wiimotes, perpendicular to the Z axis (Society_of_Robots, 2008).*

2.2 CVEclient and CVEserver

The CVEclient was used to visualise the shared virtual world. Rendering was done using the open-source library OpenSG (Reiners and Voss, 2008). Grabbing and moving virtual objects, as well as navigating through the scene were supported. Motion tracking of the user's head and hand allowed interaction with the virtual world. A person connected via a remote CAVE was represented by a computer-generated character, referred to as avatar. The realism of an avatar's appearance was increased by mapping photographs of real humans onto the 3D polygonal mesh which outlined the avatar's model. Dynamic head and arm articulation has been enabled by providing separate body parts for the head, hand, upper- and lower-arm parts. The head and hand coordinates were controlled directly from the tracker data. Animation of the remaining arm parts was implemented by applying a simple inverse kinematic algorithm. During the experiments, we used the original head tracking, while we swapped the hand tracking with our Wiimote-based implementation.

The CVEserver had two functions. Firstly, it acted as login server, similar to a directory server, where a client can chose which virtual world to join. Secondly, it acted as relay server, passing all communication between CVEclients that joined the same virtual world in order to synchronise their shared state. This could have been solved on a peer-to-peer basis in a more scalable manner. However, using a relay server simplifies firewall administration and moves the overhead for broadcasting network messages to all peers connected to the server.

Typical measured network delay between the CVEclients ranged between 36 to 42 ms, while the actual end-to-end latency was around 120 to 160 ms. The end-to-end latency includes the time it takes, from the moment the tracker's data are acquired, to transmit these data to the CVEclient, pass them via the CVEserver to the receiving CVEclient, apply them to the virtual scene, until they are finally rendered on the screen. An audio link-up between the remote users was provided using Skype®.

2.3 Measurement of Accuracy

Measurement of accuracy was carried out by comparing the errors generated while one participant followed a pre-defined trajectory using either the IR pen or the CAVE standard wand (used as reference). The trajectory to follow was made visible to the participant as a solid closed line, which the participant was asked to trace in a way similar to a wire loop game, repeating the process 5 times. A 3D pointer in front of the IR pen, or the wand, allowed to receive feedback on the pointer position. The errors between tracked and actual positions were calculated and normalized over the actual position in order to have a normalized error percentage:

$$E_{norm} = \frac{D_{tracked} - D_{actual}}{D_{actual}} . \tag{2}$$

Where $D_{tracked}$ is the distance from the origin tracked using either the IR pen or the wand and D_{actual} is the actual position where the tracked point should have been, i.e. the loop's radius. The E_{norm} distribution while using the wand was compared at a 5% significance level with the E_{norm} distribution while using the IR pen in 6 different settings: filters on or off together with number of previous positions averaged set to 1 (no average), 10 and 20: $IR_{on,\ 1,\ 10,\ 20}$; $IR_{off,\ 1,\ 10,\ 20}$.

2.4 Relevance to Rehabilitation

Among the different applications which were considered, including 3D drawing, we decided to implement a rehabilitation scenario. In this application, which targets upper limb rehabilitation, one participant simulated the person receiving therapy (referred to as local user), moving the IR source to interact in the virtual space as instructed by a remotely located therapist. The actions and movements of the local user were also available to the therapist in real time. One scenario provided the local user with a set of objects located at different reach lengths. The local user was instructed to pick and place these objects in a close-by container. A screenshot from a recorded virtual session is shown in Figure 3, while the CAVE environment at the 'therapist' site is shown in Figure 4. Locking and unlocking the object's position (pick and place) with the IR pointer was controlled by the local user by pressing a button on the wand, but was only allowed to happen when the IR-controlled pointer was moved by the local user so that it intersected the object's volume. Different exercises can thus be designed to cover specific range of movements of the upper limbs by placing objects at different distances or asking the local user to trace specific paths with varying level of difficulty.

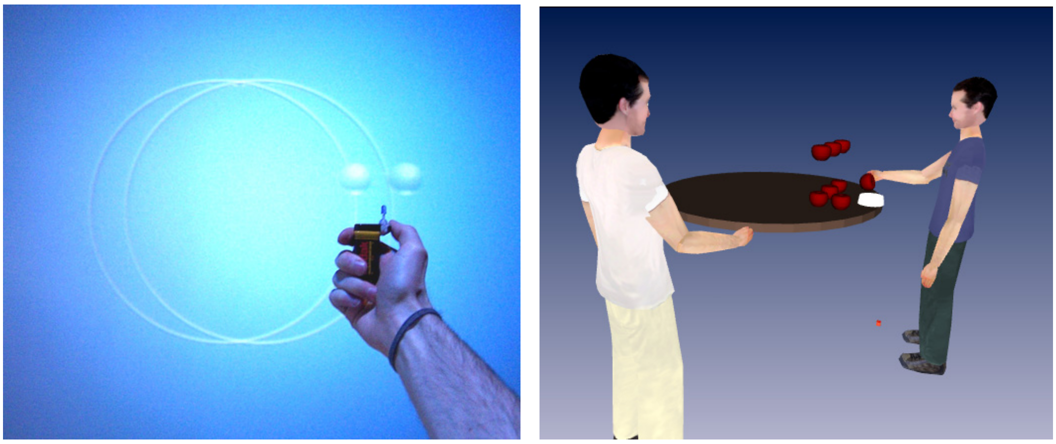


Figure 3. *Left: Accuracy tests with IR pen. Right: Rehabilitation scenario. The participant playing the patient role was instructed to pick each apple in turn and place it in a bowl.*

3. RESULTS

The pilot trials showed that IR source did not appear to interfere greatly with the IR emitters that synchronize the CAVE shutter glasses, consequently perception of the 3D scene was not disrupted. It was noticed however that the IR pointer was noisier than the equivalent wand-controlled pointer when the number of previous points averaged was less than 10. For an averaged number of points equal to 10 or above, the movement of the IR-controlled pointer was smooth, although the lag between the actual position of the hand and that of the 3D pointer increased. A value of 20 average points introduced a lag that was still comfortable to cope with at slow speed but was noticeable for reasonably quicker hand movements (speed > 1 m/s).

Variances between the E_{norm} distribution using the wand and the IR pen were different in all cases except for $IR_{on,\ 20}$ (n_1 = 1627 samples, n_2 = 1179 samples; P = 0.193). Means between the wand and IR pen populations were different in all IR settings ($P \leq 0.01$). The analysis also reveled that the variances for $IR_{on\ 1}$ (P = 0), $IR_{on\ 10}$ (P < 1E-5), and $IR_{off\ 1,\ 10,\ 20}$ (P = 0) were statistically less than that of the wand population.

As the Wiimote base was not movable, the capturing volume, i.e. the volume inside which an IR source would be visible by both Wiimotes, was dependent on the Wiimotes field of view. For Wiimotes mounted 19 cm apart on one of the cave walls (total height about 2.4 m), an approximate volume of less than 0.5 m^3, centered in the middle of the CAVE volume, was visible by both devices. This visible volume allowed relative easy movement during the accuracy tests (loop diameter was 30 cm approximately) and during pilot tests in the rehabilitation scenario.

Finally, the position of the IR pointer in the virtual environment depended on the accurate specification of the Wiimotes origin in the GUI. Several attempts were required during calibration to identify the correct parameters that reflected the movement of the real IR source on the virtual 3D pointer.

4. DISCUSSION

The statistic analysis revealed that the error variability while tracking a loop figure was significantly less for the IR populations than for the wand in most cases. However these results have to be interpreted carefully as it is possible that, when using the wand, the position of the virtual 3D pointer as well as its size in respect to the real wand may have influenced the variability of the wand population. For example if the wand is perceived to be too big relatively to the virtual pointer, or the pointer too far away, the user may be induced to make several positional adjustments compared to a case when it is not.

When using the IR source, increasing noise when none or less than 10 points averaging was used, could be explained by considering that the resolution of the CAVE wall and that of the Wiimote camera are the same (1024x768 pixels). However the dimensions of the CAVE projection wall are 3 m x 2.2 m compared to few millimeters on the camera. This means that a small movement seen on the camera's viewing plane can be translated into a relatively larger movement on the CAVE wall, hence the noisier response.

The attempts to specify the correct parameters that identify the Wiimotes location can cause unwanted delays. For this reason a different way of calibrating the system will be sought in future applications. This includes moving an array of IR sources (for example LEDs), whose geometrical arrangement is known beforehand, in front of the Wiimotes in a way similar to that used by some commercial motion capture systems. During the pilot tests it was found that the capturing volume available allowed tracking the full range of motion of the elbow while the shoulder was flexed to reach objects placed in front of the subject. Movements involving motions of the shoulder in the frontal plane, or involving subjects walking around the CAVE can also be tracked provided the Wiimotes support rotates about its vertical axis. Although this solution would increase the cost of the tracking mechanism, it is reasonably easy to implement using a single motor that is controlled to compensate for the error between the IR source on the Wiimote's view plane and the plane's centre.

Tele-rehabilitation can benefit from inexpensive motion capture as the movements of somebody receiving therapy can be sent to a therapist located in a different site in real time at a reasonably low cost. In this pilot application we tracked a single IR source; however multiple IR sources can also be used. The advantage of tracking multiple IR sources is that joint movements can be calculated if the sources are attached to specific bone landmarks. The 3D coordinates of multiple sources can be calculated from 2 Wiimotes as long as the sources are easy to distinguish on the Wiimote's view plane. Multiple Wiimotes can be used when this is no longer possible. This can be done at low cost if the sources are no longer active but passive reflectors. The alternative to using an IR pen is to use a passive reflective marker and an IR lamp around every IR camera. A solution is currently being built that allows this.

The immersive virtual environments we use become impractical and expensive if remote rehabilitation of a large number of individuals is envisaged. However, the proposed technological framework has the advantage of being easily scalable to allow home-based rehabilitation. In this scenario the server and client software would reside on desktop PCs. The therapist would connect remotely from his hospital-based PC to the patient's home PC, which is equipped with the motion-capture hardware described above. An interactive rehabilitation program can thus be created at a relatively low cost while reducing the patient's need to travel. To improve this rehabilitation system, it is possible to provide a set of feedback measurements. These include the normalized error cited above, the range of motion of selected joints, e.g. the elbow, and the total length traveled by the hand segment. These feedback measures can be conveyed by the therapist in real time via the audio link to stimulate patient motivation and involvement.

Figure 4. *View of the remotely-connected CAVE and the participant playing the therapist role. The objects' projections are visible on the front screen.*

5. CONCLUSIONS

We proposed an inexpensive motion-capture solution integrated into an immersive virtual environment which has the potential to assist remote movement-based rehabilitation. The proposed motion-capture solution has the advantage that hardware parts are relatively inexpensive compared to a commercial motion capture system, since only a minimum of two Wiimotes and an IR source are needed to perform triangulation in 3D. The application link-up can allow a therapist in one location to look at the motions of a patient in a remote location and to instruct interactively via an audio link already present in the CAVE systems. The therapist can also provide information related to the patient performance, thus increasing participation and motivation. Software scalability and lightweight tracker hardware make the system portable to desktop applications and suitable for home-based rehabilitation.

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Virtual reality rehabilitation – what do users with disabilities want?

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ABSTRACT

This paper will discuss preliminary findings of user preferences regarding video game and VR game-based motor rehabilitation systems within a physical therapy clinic for patients with SCI, TBI and amputation. The video game and VR systems chosen for this research were the Sony PlayStation® 2 EyeToy™, Nintendo® Wii™, and Novint® Falcon™ and an optical tracking system developed at the Institute for Creative Technologies at the University of Southern California. The overall goals of the current project were to 1) identify and define user preferences regarding the VR games and interactive systems; 2) develop new games, or manipulate the current USC-ICT games to address these user-defined characteristics that were most enjoyable and motivating to use; and 3) develop and pilot test a training protocol aimed to improve function in each of the three groups (TBI, SCI and amputation). The first goal of this research will be discussed in this paper.

1. INTRODUCTION

Individuals with Traumatic Brain Injury (TBI), Spinal Cord Injury (SCI), and amputation often experience impairments with balance and proprioception (Tyson and Selley 2006), sensation, cardiovascular fitness (Potempa, Lopez et al 1995), coordination and motor control (Duncan, Studenski et al 2003), and muscle strength (Duncan, Richards et al 1998). These impairments present obvious impediments to a functionally independent lifestyle, impacting mobility, performance of activities of daily living (ADL), and participation in leisure activities. Furthermore, an individual's sense of self-efficacy is hindered, often leading to an increasingly sedentary and isolated lifestyle (Riva 1998). Opportunities to participate in regular exercise are especially important for groups less physically active than the general population and more prone to secondary complications such as pain, fatigue and de-conditioning (Rimmer, Riley et al 2001).

One method of intervention currently receiving wide spread attention is the use of Video games and Virtual Reality (VR) systems for rehabilitation purposes. These systems demand focus and attention, can motivate the user to move, and provide the user with a sense of achievement, even if they cannot perform that task in the 'real world'. Current research indicates that motor function can be recovered or improved via a repetitive task-oriented motor training regimen in which an individual performs activities that target specific relevant movement, and is intensified in a hierarchical/progressive and optimal fashion based on patient progress and presents the client with a challenge (Winstein and Stewart 2006). Early research suggests that VR game-based technology can be used to improve motor skill rehabilitation of functional deficits including hand function (Boian, Sharma et al 2002; Chuang, Huang et al 2002; Adamovich, Merians et al 2004; Dvorkin, Shahar et al 2006) and walking (Fung, Malouin et al 2004; Fulk 2005; Baram and Miller 2006; Fung, Richards et al 2006). However, clinic and home-based systems need to be affordable and easy to deploy and maintain, while still providing the interactional fidelity required to produce the meaningful motor rehabilitation activity needed to foster transfer to the real world. Early research in the area of VR has used complicated and expensive systems to assist people to relearn how to move. These high-end laboratory-based systems do not meet cost and deployability requirements. A new area of research aims at assessing how off-the-shelf VR devices such as the Nintendo® Wii™ can be used in rehabilitation. While these games were not designed with rehabilitation in mind, they have the advantage that they are affordable, accessible and can be used within the home. The attitudes and opinions of people with disabilities who use these devices are not known. The overall goal of the current research is to employ user centered design process to develop VR games that improve sensorimotor function in individuals with disabilities and thus, as a first step, the research explored the opinions and attitudes, of individuals with disabilities, when using four different off the shelf, low-cost VR games and interfaces.

The goals of our current project were to 1) identify and define the characteristics of the games and 4 interactive systems (Sony PlayStation® 2 EyeToy™, Nintendo® Wii™, Novint® Falcon™, and the optical webcam tracking system) that were most enjoyable, user friendly, and motivating for individuals with TBI, SCI and amputation; 2) develop new games, or manipulate the current games to address these user-defined characteristics gathered during the first part of the research; 3) develop and start a training protocol that will improve functional ability in each of the three groups (TBI, SCI and amputation). This paper will present the findings from the focus group research.

2. METHOD

2.1 Subjects

A sample of convenience was selected from patients attending outpatient physical therapy at a local rehabilitation clinic. Participants were included if they 1) had sustained a catastrophic event (TBI, SCI or Amputation) more than one month prior to admission; 2) had no history of seizure; 3) were aged between 18 and 75 years old; 4) did not have serious uncontrolled medical complications; and 5) did not demonstrate pain that would limit their participation. All participants consented to voluntarily participate in this study. This study was approved by the University of Southern California Institutional Review Board.

2.2 Virtual Reality systems and demonstrations

During the focus group, participants were provided with demonstrations of the optical tracking system and standard games from the Sony PlayStation® 2 EyeToy™, Nintendo® Wii™, and Novint® Falcon™.

2.2.1 Sony PlayStation® 2 EyeToy™. The *Sony PlayStation® 2(PS2) EyeToy™ (Sony, 2004)* is a commercially available VR gaming system that uses a video capture interface to allow the user to interact directly with objects projected onto their own television screen. Hardware components for this system include a color digital camera device with USB interface (manufactured by Logitech, an OmniVision Video Device with an OmniVision sensor), a PS2, a DUALSHOCK 2 Analog Controller with pressure sensitivity, a powerful processor and graphics accelerator, an internal hard drive for data storage, and the EyeToy™: Play 2 disc. The total cost of the system is less than $200. The system uses motion and color-sensitive computer vision to process images taken by the camera. As the user moves his/her body, a USB connected camera digitizes and then superimposes the players' real-time likeness image on the television screen, with a graphic overlay of a virtual surrounding. Objects within the game environment move and react when contacted by the user's image (Figure 1.) creating an interactive experience between the two. The player is not required to hold a device and often uses his/her hand as the tool (racquet) to interact with the game. Sound and visual feedback indicate the success or failure of movement relative to the game task. The EyeToy™: Play 2 has 23 different games, each presenting similar movement challenges: accurate, target-based upper extremity motion, motor planning, dynamic sitting and standing balance, and eye-hand coordination. The movement tasks are multi-planar and multi-directional, with rotational and diagonal components, mimicking essential aspects of functional movement. Games can be played from a sitting or standing position. Most of the EyeToy™ games have three levels (easy, moderate, difficult) and cannot be manipulated to meet the needs of the user.

Figure 1. *The Sony PlayStation® 2 EyeToy™ (Sony, 2004), Table Tennis Game. (www.gamasutra.com and a248.e.akamai.net)*

2.2.2 Nintendo® Wii™. The *Nintendo® Wii™* uses a PowerPC based Broadway processor, has 88MB main memory and 512 MB built in NAND flash memory which can be expanded using SD card memory storage. The Wii™ uses a 12 cm Optical Disc and an 8cm Nintendo® Game Cube game disc. It has a 512 MB internal flash memory, secure digital card and a memory card. The Wii™ also contains an SD card that can be used to back up saved game data. The total cost for this system is approximately $400.00. To sense its position in 3D space, the "*Wii™* Remote" uses both accelerometers and infrared detection (via an array of LEDs) allowing for both gestures and button press to control the game. The *Wii™* currently has over 275 games to choose from with more games in development for release in the near future. The Wii™ system is different from the EyeToy™ in a number of ways. The user controls an avatar that appears in a virtual gaming environment on the television screen (Figure 2). This avatar can be made to appear in the likeness of the user and has been given the name "Wii™Me". Characteristics that the user can change on the avatar to make its likeness more realistic includes skin color, hair style, glasses, eyebrows shape and color, eye shape and color, clothing, and size. This "Wii™Me" is saved with the users name and can be used to play on all subsequent sessions. The avatar often appears in a ghost like version on the screen so that the user can see the objects or environment behind the avatar. In some of the games, the player is given the option of a "fly-over" to view the entire playing field. For example, in the Wii™ Golf game, before the player's avatar approaches the ball, the player is given a view of the entire hole so that they know how best to hit the ball. The player is given the option to select from a variety of golf clubs and to change his position and line of trajectory once the ball is hit. As the player swings the "Wii™mote" as a golf club, the angle and speed with which the player moves the "Wii™mote" will affect the distance and direction of the ball. The player is given feedback regarding direction and force once the swing is completed. Lastly, the player receives feedback via a vibration of the "Wii™mote". This vibration is not specific to any one game, but rather provides the user with feedback regarding contact with the target or ball. Most games within the Wii™ have a number of levels of difficulty built in. These levels cannot be manipulated or changed to meet the needs of the users.

Figure 2. *The Nintendo® Wii™ Golf and Bowling game.*
(www.sfgate.com, www.frequencycast.co.uk/images, www.media.gwn.com/reviews)

2.2.3 Novint® Falcon™. In the real world, falcons prey on mice. Thus the developers of the *Novint® Falcon™* named this device the "Falcon" as they believe it will revolutionize and potentially replace the traditional computer mouse as a game controller. This device sells for just under $200.00. This type of controller revolutionizes 3D touch in that the *Falcon™* provides haptics (sensory feedback during gaming interaction). When using this device, the player feels weight, shape, texture, dimension and force of the object, allowing for more "natural" play. For example, if playing a ball catching game, the player feels the impact of the ball coming into contact with their hand. The device uses interchangeable grips that move in 3D and interact with objects on the screen. Once the controller comes into contact with the virtual object, the computer updates currents to the device's motor, resulting in a force applied to the handle that is felt by the user. The current in the handle is updated 1000 times per second. This device can be used in the place of a mouse with off-the-shelf computer games to enhance user feedback as well as 19 downloadable mini- games specifically developed by Novint®.

Figure 3. *The Novint Falcon (www.technabob.com).*

2.2.4 Optical tracking system. The low cost optical motion capture system employs off the shelf Logitech Web cameras that can track three, five and six degrees of freedom of movement from low cost LED's attached to the body or to relevant objects (i.e., handheld "jogging" weights). The system utilizes a combination of single camera+dual LED, dual camera+single LED, single camera+single LED that can be connected to any PC with Windows 2000/XP. This set-up costs less than $100. Seven games/tasks have been designed and include a reaching task, supination/pronation game, elbow flexion/extension, shoulder flexion/extension task). This system has been developed by computer engineers at the University of Southern California, Institute for Creative Technology to allow for a more user-centered game environment in which the game components can be easily manipulated and customized to an individual's abilities and needs. For example, during the "Tux Racer" game, the user must control a penguin as it skis down a mountain, avoiding trees and picking up "Herring" along the way. The "Tux Racer" is a free 3D game that is typically controlled using a standard mouse and/or arrow keys on the keyboard. Points are acquired by collecting Herring, avoiding trees, and by the speed in which the user completes the game. When the LEDs are connected to a player's shoulders, this game becomes a balance and motor control task. As the player leans to the left and right, the penguin moves to the left and right. As the player leans forward, the penguin speeds up, and slows down when the player leans backward. This game can be made more or less challenging by changing the range in which a person must lean to the left or right in order to make the Penguin move to the left or right and by making the player lean farther forward or back to change speeds.

Figure 4. *Tux Racer screen shot (www. gd.tuwien.ac.at/.vhost).*

2.3 Outcome Measures

The outcome measures used in this study included a Preferences Questionnaire (Figure 5) Usability Questionnaire (Figure 6), Likeability Questionnaire (Figure 7), and focus group questions.

2.4 Procedure

Following a demonstration the participants trialed the following seven games: EyeToy™: boxing and soccer, Wii™: golf and bowling, Novint™: baseball and target shooting, USC-ICT modified "TuxRacer" game. They completed questionnaires regarding their perception of each system's usability, appeal and enjoyment. In a focus group format, the participants were asked a number of questions. Sample questions from focus group include: 1) If you could have any game created just for you, what would it be? 2) Is it important to you to make an avatar that looks like you? 3) Should the avatar be disabled or be in a wheelchair? 4) Do you like playing using the first person view? 5) Do you feel like you had control over the game? 6) Did you feel you received enough feedback from the Wii, EyeToy, Falcon and ICT games? 7) How did you feel about the graphics, were they helpful, overwhelming, enhancing to the game or interfering with your ability to play the game? 8) Do you prefer graphics that are realistic or more "cartoonish"? 9) How did you feel about the auditory feedback and the music playing in the background of the games? 10) Are the games too simple, too complex, or just right? 11) What do you perceive as the barriers to using these games in rehabilitation? 12) How do you feel about the levels of difficulty within the games? 13) Were you bored playing the games? Participants were then given the opportunity to provide ideas for improvements and comment about what they found difficult, what they liked and what they thought would be a good addition to each of the systems and games. The focus groups were videotaped and the dialogue was transcribed.

1= Most Favorite 4= Least Favorite	Novent Falcon	EyeToy	Wii	ICT/USC
Overall preference	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Graphics	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Usability	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Likelihood of playing	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Ease of setup	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Color Scheme	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Characters	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Control	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Sound	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Interface device (hand control vs body movement)	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Level of enjoyment	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Level of engagement	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Ability to interact with environment	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Level of difficulty	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Similarlity to real life	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Responsiveness of device	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Accuracy of controlling/interface/interacting device	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
This device is most fatiguing to play	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4

Figure 5. *Preferences Questionnaire.*

		Strongly Disagree				**Strongly Agree**
1	The EyeToy has a distinct advantage because it projects the players image on the screen.	**1**	**2**	**3**	**4**	**5**
2	The sensory feedback from the Novent Falcon is helpful	**1**	**2**	**3**	**4**	**5**
3	I would like to use a pen/tablet to interact with the games	**1**	**2**	**3**	**4**	**5**
4	I would like to battle others when playing the games	**1**	**2**	**3**	**4**	**5**
5	I am extremely motivated to exercise.	**1**	**2**	**3**	**4**	**5**
6	I will be more motivated to exercise if I was playing this game	**1**	**2**	**3**	**4**	**5**
7	I would rather interact with a character that looks human	**1**	**2**	**3**	**4**	**5**
8	I would rather interact with an avatar	**1**	**2**	**3**	**4**	**5**
9	Because there are too many barriers to using this technology, I am not likely to use it for rehabilitation	**1**	**2**	**3**	**4**	**5**
10	The devices often did not permit me to move the way I intended to	**1**	**2**	**3**	**4**	**5**

Figure 6. *Likeability Questionnaire.*

	Strongly Disagree				Strongly Agre
I think I would like to use the device frequently	1	2	3	4	5
I found the device unncessairly complex	1	2	3	4	5
I thought the device was easy to use	1	2	3	4	5
I think I would need the support of a technical person to be able to use device	1	2	3	4	5
I found the various functions in the device were well integrated	1	2	3	4	5
I thought there was too much inconsistency in the device	1	2	3	4	5
I would imagine that most people would learn to use this device very quickly	1	2	3	4	5
I found the device very cumbersome to use	1	2	3	4	5
I felt very confident using the device	1	2	3	4	5
I needed to learn a lot of things before I could get going with the device	1	2	3	4	5

Figure 7. *System Usability Questionnaire.*

3. RESULTS

3.1 *Participants*

The study involved discussions from a focus group study consisting of nine participants with SCI (n = 4), TBI (n = 4) and Amputation (n = 1), four females, five males with a mean age of 55.89 ± 7.67 years. The participant demographics are listed in Table 1.

Table 1. *Participant Descriptive Statistics*

Subject Number	Gender	age (years)	Time Since Injury (months)	Diagnosis	Employed	Own Computer	Play Video Games
C-1	Male	65	6	CVA	No	Yes	No
C-2	Female	49	21	CVA	No	Yes	No
B-1	Female	69	25	Brain Tumor	No	Yes	No
C-2	Female	61	47	CVA	No	Yes	Yes
S-1	Male	53	120	SCI	No	Yes	Yes
S-2	Male	55	71	SCI	No	Yes	Yes
S-3	Male	50	12	SCI	No	Yes	Yes
S-4	Male	55	42	SCI	Yes	Yes	No
A-1	Female	46	11	Amputee	No	Yes	Yes
mean		55.89	39.44				
S.D.		7.67	36.71				

3.2 *Preferences*

The participants ranked the four VR systems from most favorite to least favorite with regard to each of the characteristics listed in the Preferences Questionnaire (Figure 5). The sums of the ranks were tallied and are presented in Table 2. In general, the EyeToy™ and Wii™ were preferred in terms of overall preference, graphics, usability, likelihood of playing, characters, control, sound, enjoyment, interactivity, similarity to real life, responsiveness to device, and accuracy. The USC-ICT developed game was preferred in terms of likelihood of playing, color scheme, control, and interface. The Novint™ Falcon was preferred in terms of ease of set-up, and engagement. The EyeToy™, Wii™ and Novint™ were all preferred in terms of level of difficulty and engagement. The games that were most fatiguing to play were the Wii™ and USC-ICT games.

Table 2. *EyeToy™, W- Wii™, N- Novint Falcon™, I- USC-ICT developed games.*

	Rank1	Rank2	Rank3	Rank4
Overall preference	E	W	I	N
Graphics	E	W	N	I
Usability	W	E	N	I
Likelihood of playing	I/E		W	N
Ease of setup	W/N		E	I
Color Scheme	I	W	N	E
Characters	E	W	N	I
Control	E	W/I		N
Sound	E	W	I	N
Interface device (hand control vs body movement)	E/I		W	N
Level of enjoyment	E	W	I	N
Level of engagement	W/N		E	I
Ability to interact with environment	W	E	N	I
Level of difficulty	N	E/W		I
Similarlity to real life	E	W	N	I
Responsiveness of device	E	W	I	N
Accuracy of controlling/interface/interacting device	E	W	N	I
This device is most fatiguing to play	W	I	E	N

3.3 *Likeability Questionnaire*

The results from the Likeability Questionnaire indicated that the participants agreed that the haptics feedback from the Novint® Falcon™ was helpful. Participants responded that they were fairly motivated to exercise, and that they would be more motivated to exercise if playing these types of games. The participants were

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neutral on responses asking if they preferred characters that looked human or interacting with the games via an avatar. Lastly, participants did not feel there were too many barriers to using this type of technology and they were able to interact with the games as they intended.

3.4 Usability Questionnaire

The participants completed the Usability Questionnaire for each of the four VR systems demonstrated and trialed in this study. In general, there was no difference among the four devices in terms of usability Participants thought the devices were easy to use, well integrated, easy to learn, and they felt confident using the devices and would use each of them frequently. The participants did not feel that the devices were cumbersome to use or needed a lot of training before using them.

3.5 Focus Group Discussion Session

The participants took part in over two hours of group discussion regarding the four devices and a brainstorming session exploring potential future VR games for rehabilitation. The participants discussed a number of benefits derived from these devices. They reported not realizing how long they had been playing, and a sense of being distracted from their disability and from boring exercise regimes. Some reported enjoying, for the first time, the added dimension of receiving feedback and rewards while playing. Further comments were that the EyeToy™ was considered more interactive than the Wii™. Many felt that using the Novint™ Falcon restricted their movements more than the other games in which larger movements were encouraged. Each game system had its own unique attributes and uniqueness and was enjoyed for different reasons. Participants felt that having a somewhat unrealistic graphics background was helpful because it made the game seem more playful. For other games, participants felt that realistic graphics and an avatar that looked similar to themselves or a video captured image of themselves would be more beneficial, especially when the goal of the game was to create a very specific movement. The group consensus was that although the participants enjoyed creating avatars that looked similar to themselves the avatar need not look disabled nor move in the virtual world via a virtual wheelchair. The ability to move between first person view, fly-over view and third person view was helpful at different times within the game environment. The participants enjoyed the feedback provided from the games, especially with the EyeToy™ game in which the user saw a visual representation of them self on the screen. Although the EyeToy™ does not provide direct haptic feedback, the participants “felt” that they had made contact with objects in the game. The feedback from the handheld devices of the Wii™ and Falcon™ game were also helpful. However, some of the movements within the Wii™ and EyeToy™ games were difficult to control and participants were often unsure if they had made the correct movement. Realistic sound and auditory feedback were thought to be helpful. Auditory feedback that was linked to occurrences within the game would also be helpful. For example, the music tempo speeds up as the user moves faster through the environment or the volume increases as the user approaches the target.

4. CONCLUSIONS

In summary, users with disabilities have distinct opinions and preferences regarding VR games and their use in rehabilitation. Most importantly, these individuals expressed a great deal of enjoyment from using these games and a desire to use them during their rehabilitation process. They found the feedback in the form of visual feedback and haptics especially helpful. Participants also discussed how each game system had its unique set of attributes. Further research is required to assess the utility of off-the-shelf gaming technology and to adapt these games in a manner that is most helpful and enjoyable for individuals with disabilities. Despite the participants stating that they would use the games just because they were fun, rehabilitation specialists are obligated to develop games that are best suited to address the specific rehabilitation needs of the individual while remaining substantiated by rigorous theoretical bases. We have already begun manipulating our existing games based on the feedback collected in this study and testing these new games in a large scale study. These tools may be very helpful in encouraging individuals with disabilities to “play” with and against family and friends, thus promoting a healthier, more active and less isolating lifestyle.

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Auditory-visual virtual environments to treat dog phobia

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ABSTRACT

In this paper we present the design, development, and usability testing of an auditory-visual based interactive environment for investigating virtual reality exposure-based treatment for cynophobia. The application is developed upon a framework that integrates different algorithms of the CROSSMOD project (www.crossmod.org). We discuss the on-going work and preliminary observations, so as to further the development of auditory-visual environment for virtual reality. Traditionally, virtual reality concentrates primarily on the presentation of high fidelity visual experience. We aim at demonstrating that combining adequately the visual and the auditory experience provides a powerful tool to enhance sensory processing and modulate attention.

1. INTRODUCTION

Virtual Reality (VR) has been employed as an alternative for in vivo exposure for the treatment of different phobias for the past decade (see Riva, 2005; Parsons and Rizzo, 2008; Cobb and Sharkey, 2006). Specific phobias have been successfully treated with VR, including arachnophobia (e.g. Carlin et al, 1997). However, few of these procedures have been conducted with VR involving multiple sensory stimulations. Modulation of perceptual processing depends on sensory inputs from all modalities, and can potentially influence perception and behaviour in multiple ways. The aim of this study is to investigate VR exposure-based treatment for cynophobia (dog phobia). We have chosen to work on cynophobia because the acoustic aspect of this phobia is much more relevant than in some other phobias, and is therefore an ideal target to test the efficacy of auditory and visual environments to generate presence and emotion. Exposure-based treatments for cynophobia can use in vivo techniques, imaginal techniques, or hybrid technique (Rentz et al, 2003). In order to treat a phobia, the virtual exposure needs to evoke genuine reactions and emotions. In the case of cynophobia, a very important component of the anxiogenic stimulus is the auditory one: dogs barking and growling are very efficient in provoking emotional reactions in any individual.

Diverse audio-based applications have been implemented in the last few years, involving 3D sound. However, the majority of these applications have been designed to work with blind persons (e.g. Lahav and Mioduser, 2002; Sanchez, 2004) or individuals with severe disability (Brooks et al, 2002). In our application, auditory information is not used as a way to supplement visual information. Because strong emotional reactions can easily be elicited through audition (Bremner et al, 1999), we want to fully exploit the potentiality of 3D audio to increase the realism and richness of the immersive environment. Humans are easily distracted by the locus of an irrelevant auditory event when their visual attention is focused elsewhere (Van der Lubbe and Postma, 2005). This implies that endogenous orienting does not suppress auditory exogenous effects, and that audition can therefore serve as a strong cue to induce emotional reactions in individuals immersed in a visual environment. Furthermore, animal sounds seem to have a stronger influence in alerting than any other sounds (Suied and Viaud-Delmon, 2008).

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Therefore, the study we present here involves technologies, models and applications linked to the use of 3D sound in VR environments. Auditory augmentation of visual environments is known to improve presence and immersion (Hendrix and Barfield, 1996). To create such environments and the corresponding content, several concepts and technologies need to be researched, developed, and/or integrated. The introduction of 3D sound also addresses the need for a better understanding of multisensory integration mechanisms. This includes complementarities or conflict between the auditory and visual senses and also with idiothetic cues (cues generated through self-motion, including vestibular and proprioceptive information).

The most natural audio technique for VR applications is the binaural rendering on headphones that relies on the use of HRTFs. HRTF refers to Head Related Transfer Function, which is a set of filters measured on an individual or artificial head and used to reproduce all the directional cues involved in auditory localization (Blauert, 1983) However, incorporating real-time updated 3D sound to VR technologies addresses several practical issues. If there is a consensus on the fact that presence is improved by 3D sound, little is known about how an auditory VE should be designed so that it does not interfere with the visual VE (Vastfjall, Larsson and Kleiner, 2002). To develop an application planned for clinical use, we therefore have to conduct several preliminary studies to know how to design an auditory environment and how to integrate efficiently the auditory component of the threatening stimulus.

The primary aim of the current study is to determine the situations in which emotional reactions can be evoked in individuals who fear dogs. A secondary aim is to test the efficacy of progressive exposure thanks to features that can be manipulated in VR only (e.g. visual contrast of the scene, presence or absence of visuals when there is a sound, coherence or conflict of the sound with the visuals, sound source localisation control, dog behavioural control etc…). We will present here all the necessary steps which guided us to choose the different components of the virtual environments, in which participants will be immersed and confronted to virtual dogs. Our final goal will be to determine whether dog phobia can be successfully ameliorated with virtual reality treatment.

Exposure techniques have to be progressive (e.g., the first time you only see a dog far away, second time it's a bit closer, third time it is next to you, fourth time you are surrounded by dogs). We have chosen to develop gradation techniques, which vary along several dimensions to manipulate the emotional component of the stimulus. In this study, we use 3D sound as a progressive exposure tool. We use different sounds of dogs, accompanied or not with visuals, graded in emotional valence through the manipulation of the light and the composition of the visual environment.

2. METHODS

2.1 Procedure

To conduct our study, we needed to select participants reporting an unusual fear of dogs. We also needed to gather information on fear of dogs to design our virtual environment and animated dogs. We therefore conducted a two-stage screening process. On the basis of this screening, we invited 10 participants to take part to the evaluation procedure of our application and selected one dog model.

2.1.1 Fear of dogs screening. In order to select our participants, we developed a preliminary questionnaire assessing fear of dogs (possible range 0-42). This questionnaire was composed of 14 items rated on a scale of 0 (no fear) to 3 (extreme fear), assessing fear in response to size of dog, activity level of dog, and physical restraint of dog (e.g. leash). Four preliminary yes/no questions were asked: "Do you have fear of dogs?", "Do you avoid dogs or endure their presence with intense anxiety?", "Are you afraid of a specific dog breed and if yes, which one?", "Does the size of dog have an effect on your fear?" Seventy-five individuals (32 females) have participated to this screening. Mean age of the sample was 31.3 years (SD=8.4).

2.1.2 Virtual dogs rating. In order to validate the threatening dog model on which our exposure protocol would be based, we first built 9 different dog models and animated them with a growling movement. We used the following dogs breed: boxer, German shepherd, pit-bull, Staffordshire, Doberman, Miniature Pinscher, Malamute, bull terrier, Great Dane. We then asked 10 participants to rate the valence and arousal of animations of these different dog models. On the computer screen, each of the 9 dogs was presented for 1 s. At picture offset, the self-assessment rulers for valence and arousal were presented. Presentation of dog models was pseudo-randomised.

2.2 Virtual environments

We use exterior and interior virtual scenes. The two exterior scenes are a street scene (see Figure 1), with cars passing by and traffic noise; and a garden scene with trees, a house, tables and benches. The interior scene is a large dark hangar, in which different industrial machinery are active and producing contact sounds.

Figure 1. *The three virtual environments used in this study. On the left, the city scene, in the middle, the garden scene, and on the right, the factory scene.*

2.3 Setup

The sessions take place in an acoustically damped and sound proof recording studio with the light switched off. The visual scenes are presented on a 300×225 cm² stereoscopic passive screen, corresponding to 90×74 degs at the viewing distance of 1.5 m, and are projected with two F2 SXGA+ ProjectionDesign projectors. Participants wear polarized glasses.

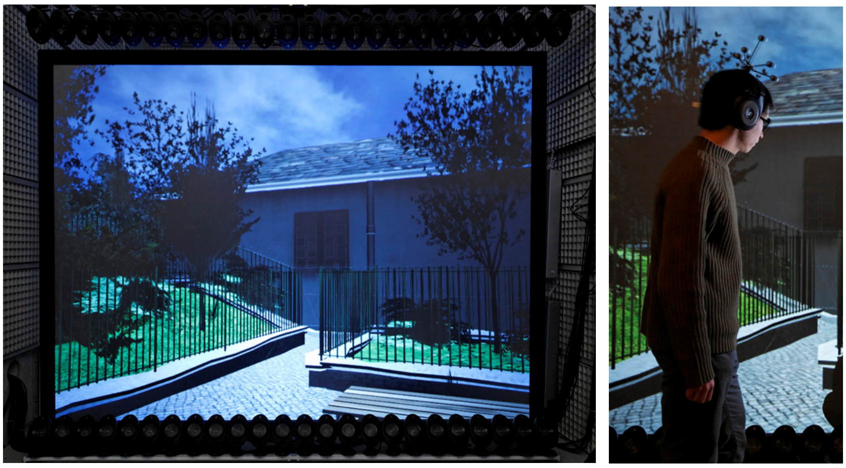

Figure 2. *Virtual Reality setup. On the left, view of the entire screen in the acoustically damped studio, on the right, a participants equipped with headphones, a head tracker and polarized glasses.*

The auditory scenes are presented through Sennheiser HD650 headphones. To provide good virtual auditory localization cues, the sound stimuli are processed through binaural rendering (Blauert 1983), using selected non-individual HRTF of the LISTEN HRTF database (http://recherche.ircam.fr/equipes/salles/listen/). Head movements are tracked so that stereo and 3D sounds are appropriately rendered. The participants are equipped with a wireless mouse to navigate in the virtual environment. With this device, they control both rotations and translations within the virtual scene.

2.4 Rendering

Virtual three-dimensional visual scenes are rendered with the OgreVR API developed by INRIA. OgreVR is the combination between the graphics rendering engine Ogre (Milne and Rowe, 2002) and the library VRPN (Hudson et al 2001), which provides a transparent interface between an application program and most of the devices used in virtual reality such as tracking systems, flysticks, joysticks etc. These 2 libraries are open source projects written in C++. The rendering machine is based on an AMD Dual Core Opteron 275 (2.2 GHz). The machine is equipped with two 2 GeForce 7950 GX2 M500 graphic cards.

2.5 Evaluation of the application

Evaluation is made according to the capacity of the virtual environments to evoke fear in participants. The final evaluation will be made with the presence scores, the Subjective Unit of Distress scores (Wolpe, 1973), and the level of improvement in fear.

2.5.1 Questionnaires and Interview Measures related to the exposure sessions. The state portion of the STAI (Spielberger et al, 1983) is used to measure the anxiety levels upon arrival at the laboratory and after completion of the exposure session. A 22-item cybersickness scale assesses the level of discomfort after exposure to VR (Viaud-Delmon et al, 2000). It comprises a list of symptoms and sensations associated with autonomic arousal (nausea, sweating, heart pounding, etc.), vestibular symptoms (dizziness, fainting, etc.), respiratory symptoms (feeling short of breath, etc.) and can also be used to estimate signs of somatisation (tendency to complain of a large number of diverse symptoms). Items are rated on a scale from 0 to 4 (absent, weak, moderate, strong). The presence questionnaire from the I-group (Schubert et al 2001) is presented after immersion.

Anxiety ratings are collected during the exposure with Subjective Unit of Distress (Wolpe, 1973). The SUDs rating is a valid self report measurement of anxiety on a 0–100 point scale. Scores of 0 represent no fear and 100 represents the most fear the individual has ever felt in their life. SUDs ratings are taken in 5 min intervals throughout the session.

2.5.2 Measures during the exposure sessions. Participants have to fulfil a task during the exposure. In each of the environment, they have to find targets and to validate them in order to go on with the exploration. In order to find these targets, they need to follow a trajectory in which they will encounter dogs.

We therefore measure the success to each task, but also count the behavioural reactions of the participants whenever they encounter a dog (step backward, freezing …).

3. RESULTS AND DESCRIPTION

3.1 Fear of dogs screening

The preliminary questionnaire obtained a mean rating of 10.4 (SD=9). There was no difference between males and females ratings. Fourteen individuals responded “yes” to the first question (“Do you have fear of dogs?”). These individuals had scores ranging from 8 to 34 (mean=23.3, SD=9.3). Therefore, this yes/no question was not completely discriminative and the total score might provide more information.

Thirty one individuals reported that they are afraid of a specific breed. Pit-bull were reported 14 times, Doberman 7 times, then Rottweiler (4), German Shepard (3) and Bulldog (3). Forty-four individuals reported that the size of a dog had an impact on their emotional reaction.

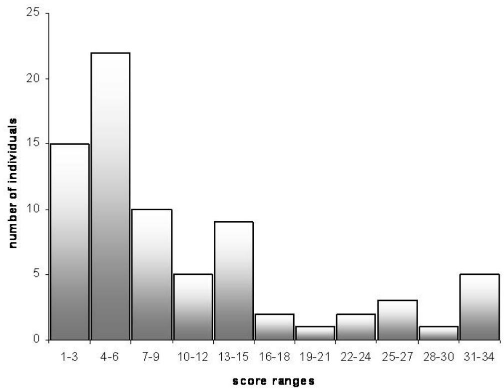

Figure 3. *Scores distribution of fear of dogs in a sample of 75 individuals.*

Participants who obtained a total score superior to 20 (values above 1 standard deviation of the mean of the total sample) were invited to take part in a diagnostic interview with a clinical psychologist. Selected individuals were then invited to further participate in exposure sessions, aiming at reducing their fear of dogs. Ten participants are currently taking part in the study.

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3.2 Virtual dog selection

Ten participants in the fear of dogs screening were further invited to evaluate 9 animated dogs, modelled after the answers gathered in the questionnaire. Surprisingly, the pit-bull model was not judged as the most negatively valenced and arousing, and the Doberman model was the most uniformly rated.

The Doberman was therefore selected as the threatening stimulus for the exposure sessions. Several animations have been developed: running, walking, seating, jumping etc. It also affords growling as well as barking, and the experimenter can control the dog animations with keys. The dog's barking and growling are spatialised in 3D.

Figure 4. *The Doberman dog model, which was selected as the dog to be included in the exposure sessions.*

3. 3 Pre-evaluation of the application: the scenarios

Participants who have been exposed to the on-going work have provided valuable comments to improve the application. The first scene to which they were exposed was the city scene. In this city, they had to find a restaurant, then to go to a cash distributor machine, after which they had to follow a dog to find the endpoint of their journey. This scene was evaluated both with a dim light with sharp shadows and a bright light. The auditory environment was composed of cars roaring, and sounds recorded in a city. Subjects met a silent dog when they walked towards the restaurant. The next dog was seating next to the cash distributor machine, growling as they were approaching. The dog they had to follow was not emitting any sound. Participants did not notice any difference across the two light conditions, and completely focused their attention on the task. Obviously, perceptual processing was enhanced by the emotional cues: the dogs in this scene were presented with a low contrast. Still, participants did not notice any difference with the scene in which the dogs were presented with a high contrast.

In the second scene, participants had to find a specific house, while walking in front of several houses surrounded by fences. Dogs were barking behind these fences. The auditory environment was composed of different outdoor sounds, including birds. While the visual environment was judged as less anxiogenic than the city, the dogs barking did elicit a high level of anxiety.

In the last scene, participants had to walk across an automatic door guarded by a dog, which would stand up and growl as they were approaching. The scene was composed of several sounds emitted by the machinery. This was judged as the most anxiogenic and the task as extremely difficult.

This pre-evaluation indicates that sensory processing and attention was modulated by the affective significance of stimuli. Participants did pay more attention to emotional stimuli, as expected. Even in a dim light, emotional cues enhanced visual processing of the stimuli.

4. CONCLUSIONS

The on-going evaluation of our application aims at testing the capacity of the virtual environments to evoke fear in participants. The final evaluation will be made with the presence scores, the SUD scores, and the level of improvement in fear. First results are very encouraging and indicate that strong emotional reactions can be elicited and mastered through a semantically gradual exposure. The preliminary evaluation showed that the environments did produce an increased perceptual processing of emotional stimuli, resulting in impairment in doing the proposed tasks. Apart from spatial orienting effects, auditory stimuli are known to increase alertness. Our application provide evidence that these effects may also be modulated by endogenous orienting, and, the other way round, that it may be more difficult to keep attention focused in the case of highly alerting stimuli. When taken into account, these specific properties of auditory stimuli can be efficiently integrated in a virtual environment to influence endogenous orienting.

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ICDVRAT 2008

Session IV

Communication & Interaction

Chair: Adam Sporka

Collaborative puzzle game – an interface for studying collaboration and social interaction for children who are typically developed or who have Autistic Spectrum Disorder

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[1,5]*www.odflab.unitn.it*, [2,3,7]*http://hw.haifa.ac.il/occupa/LIRT/*,
[4]*http://tcc.itc.it/people/pianesi/index.html*, [6]*http://tcc.itc.it/people/zancanaro/*

ABSTRACT

In this paper we present the design and some initial observations of the Collaborative Puzzle Game, an interactive play system designed with two main purposes: 1) to study social interactions and collaboration in boys with Autistic Spectrum Disorders and with typical development, and 2) to test the feasibility of the system as an instrument for the rehabilitation of social abilities of boys with ASD. Designed to run on the DiamondTouch, an interactive table supporting multi-user interaction, the CPG allows to implement "enforced collaboration", an interaction paradigm where actions on digital objects that can be performed only through the simultaneous touch of two or more users.

1. INTRODUCTION

1.1 Autistic Spectrum Disorder

Autism spectrum disorder (ASD) is a pervasive developmental disorder that is characterized by three main features including 1) a major impairment in social interaction, with difficulties in forming and maintaining social relationships, 2) a qualitative impairment in verbal and nonverbal communication and 3) a restricted repertoire of activities and interests, together with the presence of repetitive behaviours (DSM-IV-TR: APA, 2000). The cognitive and learning abilities of people with ASD can vary from gifted to severely challenged. ASD begins before the age of 3 years and lasts throughout a person's life. It occurs in all racial, ethnic, and socioeconomic groups and is four times more likely to occur in boys than girls. It currently affects approximately of one child in every 150 (ASA, 2008).

The social deficits of individuals with ASD detract from their full participation in school, work, and leisure activities in the community. These deficits are not only a matter of verbal and non-verbal communication difficulties but also include a core impairment, "social cognition". People with ASD are challenged in perceiving the thought processes of other people, which is crucial for understanding the feelings, intentions, and thoughts of others. Social cognition is compromised even in gifted individuals with ASD limiting their occupational opportunities. Rehabilitation efforts focus on finding ways to promote interpersonal skills in people with ASD, who find social interaction with others confusing and uncomfortable (Sigman and Ruskin, 1999). Social skills can be practiced through modelling, coaching, and direct practice of their application.

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People with ASD also show certain strengths including visual-spatial abilities which are "an islet of ability" as first observed by Shah and Frith (1983), and confirmed by several experimental studies of visual-spatial tasks such as the block design subset of the Wechsler scale (Shah and Frith, 1993) and other visual search tasks (e.g., Shah and Frith, 1983; Mottron et al., 2003). The visual modality is often used to facilitate learning and independent performance of persons with ASD since such aids and cues can help to organize behaviour, understand task demands, and to sequence actions (Quill, 1997). This is important for individuals whose visual processing is strong relative to auditory processing.

1.2 Computer Intervention for ASD

During the last decade a number of experimental studies were carried out to assess the utility of innovative technologies for people with ASD. These studies were mostly conducted by interdisciplinary teams and considered a variety of different devices and interaction environments, such as virtual reality (Sik Lányi and Tilinger, 2004; Revel et al., 2002; Takahashi et al., 2004), robotics (Dautenhahn, 2003), multimodal interfaces (Bernard-Opitz et al., 2001), handheld devices (e.g. Sano et al., 2002), and collaborative technologies (Piper et al., 2006; Gal et al., 2008). The studies supported their usefulness and effectiveness as a means for supporting and acquiring social and interactional abilities in children with ASD. Children with ASD seem to be highly motivated by computer-based activities (Chen and Bernard-Opitz, 1993; Hart, 2005), and have made significant gains in learning vocabulary (Heimann et al., 1995; Moore and Calvert, 2000), emotional expressions (Silver and Oakes, 2001) and social problem solving (Bernard-Opitz et al., 2001). Moore (1998) suggested that computer interventions appear to be particularly appropriate for people with ASD since focusing on a computer screen, where only necessary information is provided, can help people with ASD to reduce distractions from unnecessary sensory stimuli. Moreover, computers are free from social demands and can provide consistent and predictable responses; this can be particularly useful for people with ASD who often find the surrounding environment confusing and unpredictable.

1.3 Objectives and Structure of the Paper

The objective of this paper is to present the design and some initial observations of the Collaborative Puzzle Game (CPG), an interactive game designed with the purpose of creating a technology-supported collaborative activity for studying collaboration and social skills in children with ASD and with typical development. The target population of the system is boys in an age range that spans from 8 to 11 years for the typically developed, while inclusion of boys with ASD extends to early adolescence, provided that their mental age corresponds to that of younger typically developing children.

The observations we report in the next sections of the paper have thee purposes: 1) to test the general feasibility of the system as an instrument for the study of collaboration both in children with ASD and with typical development and possibly for the enhancement of social abilities; 2) to verify whether the design choices we adopted for the interface (e.g., shape and dimensions of the digital elements of the game, use of audio and visual feedbacks in response of actions performed by players) were appropriate in terms of usability, intuitiveness and enjoyability, and 3) to test if and how a particular interaction paradigm called "enforced collaboration" (described in Section 2.3) has an effect on the way children interact and collaborate on the CPG.

During the design of the system we followed an iterative procedure consisting of the development, testing, and refinement of the interface on the basis of observations made with users. At each stage different groups of boys were involved and observed while playing with the CPG, both individually and in pairs. In Section 2.4 we report the results of a first group of participants who were involved in the selection of the stimulus set. In Section 3 we report on the usability of the system. In Section 4, we summarize two case studies, one with children with typical development and one with children with ASD, conducted after the development of the current version of the CPG interface. Finally, we conclude with a summary of the results to date.

2. COLLABORATIVE PUZZLE GAME

2.1 Hardware

The DiamondTouch Table (DT) is a multi-user, touch-and-gesture-activated screen for supporting small group collaboration produced commercially by Mitsubishi Electrics Research Laboratories (Dietz and Leigh, 2001). Images can be top-projected to its wide horizontal surface through any kind of commercial projector. The DT can determine, through a capacitive coupling system, which part of the surface is being touched and can identify up to four users simultaneously. The system does not require any additional devices, such as pens or stylus, and users can interact directly through finger touch or gestures. Several behavioural and interaction studies have already been conducted using this device involving adults (Everitt et al., 2004; Kobourov et al., 2005; Wang et al., 2005), children (Zancanaro et al., 2007), and children with high functioning autistic disorders (Gal et al, 2008; Piper et al., 2006). These works show the advantages coming from the use of the DT table in interaction studies:

- The big touch screen allows direct manipulation of digital objects on the surface. It also gives the possibility of using larger shapes and objects, or a greater number of objects, as compared to normal screens.
- Its multi-user property allows the simultaneous use of the interface by more than one person. The DT seems to be particularly suited to support tasks and situations in which social abilities and interaction play a major role.
- Being a table-top device, it allows for styles of work and interaction that are very common in scenarios such as the school and clinical environments.

Furthermore, the DT table features a very precise log system that makes it possible to track all the actions performed on the surface, making analysis of interaction much easier. The logs are XML files containing the list of the actions performed, along with information about the experimental condition. A time stamp is associated to each action, making it easy to run temporal analyses on interactions.

2.2 Software

The CPG is an interactive application developed at FBK-irst with the purpose of studying collaboration and social abilities in dyads consisting of children with ASD. The game resembles a traditional jigsaw puzzle (an activity that primarily involves visuo-spatial skills) the only difference being that pieces have a rectangular shape instead of the traditional interlocking curved shape, as shown in Fig. 1. At the beginning of the game, the following objects appear on the table surface: 1) A variable number of puzzle pieces; 2) a target picture shown in the upper part of the DT, which represents how the puzzle looks like once correctly completed; 3) a solution area, positioned in the region of the surface proximal to participants and horizontally centered, which is where pieces have to be dragged to complete the puzzle. The solution area is divided in a number of invisible cells corresponding to the positions where puzzle pieces can be released. The number of the cells corresponds to the total number of pieces.

The experimenter can set the game (e.g., different play conditions, number of pieces, dimensions of the solution area, and the picture to be shown) by means of a settings panel. The actions that players can perform are relatively simple. A puzzle piece can be dragged to a new position (either to the solution area, or away from it). Whenever a piece is released within the solution area, it anchors to the cell of the solution area closest to the releasing position. To remove a piece from the solution area, it is sufficient to drag it away and release it at any other position on the surface. Attempts at releasing a piece over a previously released one end in failure, with the former piece starting again to float around.

Several visual and auditory feedback signals have been implemented to make the interaction more understandable, motivating and fun. When a piece is released in an incorrect position on the solution area, an unpleasant buzz is played and a red halo surrounds the piece until it is removed. A pleasant sounding beep and a green halo (which disappears after a few seconds) are associated with the correct positioning of a piece within the solution area.

2.3 The Enforced Collaboration Paradigm

One of the goals of this study was to investigate in a preliminary way the effect of an interaction paradigm called “Enforced Collaboration” on the way people work together on collaborative tasks. In particular our interest is to focus on its effect on social interaction. Enforced collaboration requires that actions on digital objects (e.g., touch, drag) to be effective must be carried out by two or more users simultaneously. Preliminary investigation with dyads of children with high functioning autism has shown that forcing the simultaneous execution of selected tasks may foster the recognition of the presence of the other, stimulate social behaviour (increased eye contact, emotion sharing, and enhanced interest toward the partner) and improve social skills (Bauminger et al., 2006; Zancanaro et al., 2005; Gal et al., in press).

The enforced collaboration paradigm is realized by taking advantage of the DT table’s capability of supporting multiple-user actions; that is, drag-and-drop, click and double-click that are executed simultaneously by more than one person. Enforced collaboration is active in the Joint Play Condition, in which puzzle pieces can be moved to the solution area only be means of a joint drag-and-drop action. In the Free Play Condition, players can move puzzle pieces individually.

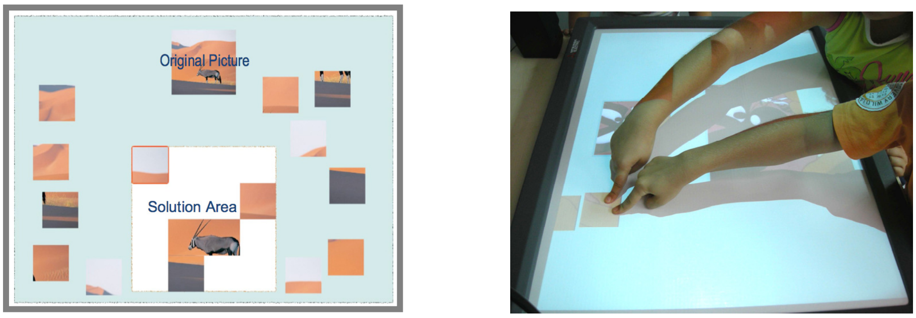

Figure 1. *The Collaborative Puzzle Game interface (left), and an example of a joint action in the "enforced collaboration" condition (right).*

2.4 Selection of Puzzle Pictures

In order to have enough pictures to select from of comparable difficulty, a preliminary study was carried. Six high resolution screen shots were extracted from an animated movie (Shrek 2, chosen during an initial survey of popular children's movies). Pictures taken from animated movies are less complex and have clearer discontinuities and contrast among the represented objects in comparison to real photographs. The pictures were edited to get the optimal size, brightness and contrast for the digital puzzle.

Fourteen typically developed Israeli boys (mean age = 9.9 years, SD = 0.77), were asked to individually complete six puzzles corresponding to the six pictures, using the CPG interface in the free play condition. The picture order was random. Complexity was defined in terms of puzzle completion time, number of errors made before correct completion, and by means of the subjective perception of difficulty rated on a ten-point Likert scale. The design was within-subject with a six-level factor (picture) and three dependent variables; age was treated as a covariate. Since no significant effects were detected by the multivariate test (MANOVA with repeated measures), the complete set of six pictures was retained.

3. USER TESTING

3.1 Objective

We conducted user studies to probe the usability of the CPG.

3.2 Participants

Twenty-two boys with typical development, aged 8 to 11 years, and three boys with ASD, aged 13 to 15 years participated in the development stage of the CPG interface. Children with ASD were diagnosed using the Autism Observation Diagnostic Scale (ADOS), had a good level of verbal communication and an IQ at the lower end of the normal range.

3.3 Procedure

All boys first engaged in an individual training phase when they completed one 16-piece puzzle. During this practice phase, the experimenter provided clarification about the on-screen digital objects and demonstrated how to interact with the interface. During the subsequent study phase, the boys played in pairs, completing two 16-piece puzzles, one after the other. In the typically developing group, six pairs played using the "enforced collaboration" condition and five pairs played using the "free play" condition. The boys with ASD (A, B and C) were paired two of them at a time such that three pairs were formed (A+B, A+C, and B+C). Each pair played completed one puzzle using "enforced collaboration" and one using the "free play" modality. All sessions were video-taped. After the sessions, the experimenter interviewed the children about their experience, probing the level of involvement and enjoyment, the difficulty/ease of use, comparisons with non-technological cardboard puzzles, willingness to play again with the CPG in the future.

3.4 Results

Both typically developing children and those with ASD appeared to find the interface enjoyable, highly intuitive, and to understand quite quickly how to interact with the elements of the CPG, often prior to an explicit explanations. As expected, the "enforced collaboration" condition made the interaction more complex, as demonstrated by longer completion times. However, none of the children found that joint actions interfered with the task, and they showed a good level of engagement. In no case did they express the desire to quit the CPG because it was boring or difficult. The use of joint actions appeared to stimulate task-related conversation, both among children with ASD and those with typical development. During the interaction, children invited their peer to join them in dragging a piece they had selected (e.g., "Let's move this one that goes there") or, as we observed in an interaction of one pair of children with ASD, to prompt working together (e.g., "Come on… help me with this, we need to do it together").

One complication was due to the way the audio-visual feedback was used. Children with ASD seemed to use feedback as planned, that is, as an aid in detecting wrongly positioned pieces. Children with typical development, however, used the negative feedback to engage in a "trial and error" process to complete the puzzle, relying more on the feedback than on their own judgment to find the correct placement of pieces. This strategy was clearly not present when feedback was not provided and children had to base their choice on comparison with the target picture. This observation led to a modification of the setting panel of the CPG such that it is now possible to independently deactivate audio or visual feedback.

4. CASE STUDIES

4.1 Objectives

In order to obtain initial data about relevant behavioural patterns emerging during the joint interaction with the CPG, a study was conducted to focus on collaboration, verbal and non-verbal indicators of social behaviour, as well as on the identification of behaviours typical for individuals with ASD that might emerge during the collaborative game.

4.2 Participants

Two pairs of boys, one with typical development and the other with ASD, participated. The boys with ASD were recruited from an afterschool program designed for children with ASD. Inclusion criteria included intact visual acuity (with corrective glasses if needed), field and intact hearing, a score ranging from 29.5 to 36.5, corresponding to a moderate severity of ASD on the *Childhood Autism Rating Scale* (CARS, Schopler et al., 1980), corresponding to a moderate severity of ASD. The parents reported that the two boys, O. (10 years) and I. (12 years), used computer games on a regular basis, did not like being stopped during such an activity, but did not have an unusual special interest in puzzles. Based on the *Beery-Buktenica Developmental Test of Visual-Motor Integration (VMI 5th ed.)*, O. showed good visual perception skills but poor motor coordination and visual motor integration skills, while I. had strong visual motor integration skills.

4.3 Procedure

Both pairs of boys completed two 16-piece puzzles in the "enforced collaboration" condition. Before the session, each boy completed one puzzle individually and was instructed, when needed, about how to interact with the interface. In the session when boys with typical development were involved, audio and visual feedback were deactivated, in order to avoid the "trial and error" strategy previously observed; when children with ASD used the CPG, feedback was activated. All sessions were videotaped.

4.4 Typically Developed Pair

The two typically developing boys (R. and B., 10 and 10,5 years old respectively) completed the two puzzles in 4.55 minutes; the number of actions initiated by the two boys was similar and decreased from the first puzzle (R. = 18, B. = 17) to the second one (R. = 12, B. = 12), showing evidence of learning while playing with the CPG. Most of the actions were suggested by R., who pointed to a specific puzzle piece before touching it or letting B. be the first to touch it. The leading role of R. was particularly evident since most of the actions were accompanied by his verbal hints. However, as the game proceeded, a balance between the actions initiated by the two players could be observed together with a "spatial specialization": the boys tended to contribute to the completion of the puzzle by picking up pieces that were closer to them than to their peer, suggesting a form of collaboration based on division of territory.

The two boys communicated verbally in order to negotiate whether R. or B.'s choice would be acted upon. For instance R. said: "No, no, let's take this one". R. joined B.'s initiated actions primarily when his own were unsuccessful. When R. did not agree with B.'s selection he verbalized this (e.g., "Wait a second, let's try this piece"). B. was less verbal than R. and spoke in a lower tone. He tended to pause to wait for R. to collaborate rather than trying to convince him to accept his choice. When R. resisted, B. tried to persuade him verbally (e.g., "Believe me, this is right"). A considerable amount of non-verbal interaction, such as visually tracking of the other's actions, waiting for the other to join the action, smiling, could be observed.

4.5 Pair with ASD

Throughout the experiment O. was non-verbal, made minimal eye contact, and usually showed neutral facial expression. He was task-oriented and did not express frustration. I. used single words and non-words during the experiment as well as high pitched sounds. He understood the task instructions once they were written. I. made minimal eye-contact and his affect was neutral to negative throughout. He was easily distracted by sounds and covered his ears after the auditory feedback he received from the table and adult upon completing the puzzle. "I" frequently bit his hand and covered his mouth particularly when he was frustrated by not succeeding to move a puzzle piece.

It took them 7.68 minutes to complete the two puzzles Overall the pair with ASD made almost twice as many actions (touch + release) in comparison to the typical pair. The number of action initiations was quite balanced between the two boys but only I. showed a decrease during the second puzzle, i.e., his selection of puzzle pieces became more effective. These data were confirmed by the higher ratio between correct and incorrect releases shown by I. (28/6) in comparison to O. (26/17).

Initially the two boys engaged in parallel attempts to move the puzzle pieces without attending to each other's actions. Occasionally one of the boys would try to move the other boy's hand away from the puzzle pieces in order to move the piece he wanted. In the same way observed for typically developing children, as the session proceeded, a gradual increase in spontaneous collaboration efforts was observed. This was apparent by a decrease in adult directed instructions (e.g. "work together") and by an increase in responses to each other's initiations. While I. rarely responded to O.'s initiations, after several verbal prompts to touch the puzzle pieces together by the adult, O. began to more consistently respond to I.'s actions and reduced his own initiations.

Individual characteristics that contributed to the pair's performance included O.'s ability to stay on-task and to be flexible in problem solving (i.e., using several fingers, two hands) and in joining I. I.'s strong visual motor integration skills enabled him to persist in initiating correct actions but his high distractibility and sensory sensitivity compromised his level of participation in the task.

4.5 Comparison of interaction patterns

The differences in interaction patterns between the two pairs included the extent of verbal negotiations, and waiting for other's response in the typical pair compared to the attempts of parallel play and hand removal strategies by the pair with ASD. For both pairs there was some visual tracking of the other user's action however these were brief in the ASD pair. Similarities in the patterns of interaction of the two pairs were: (1) an increase in collaboration as the session progressed, (2) one boy tends to lead and dominate the interaction while the other tends to follow, and (3) the leading boy tries verbally or non-verbally to convince the other boy to select his choice. Although completion times differed dramatically for the two pairs, the total percent of correct releases did not.

5. SUMMARY AND CONCLUSIONS

We have presented the design process of the CPG, a system developed with the purpose of studying collaboration and social interaction among children with ASD and children with typical development. We also presented some initial observations conducted with users that helped to structure the iterative process of development of the system.

Our initial results suggest that both children with typical development and those with ASD enjoyed using the CPG, and were readily able to learn and execute the various functions of the game within one session with minimal explanations. Initial observation of the videotaped records indicates that there is a difference between children with typical development and those with ASD in the way they use the CPG and in their interaction patterns. An increase in collaboration as the sessions progressed for both typical children and those with ASD was observed. Our tentative conclusion is that the CPG encourages children to interact, whether they have ASD or not.

All children with ASD have, by definition, social deficits. These deficits have an impact on their ability to fully participate in school, work, and leisure activities in the community. The use of an intervention tool such as the CPG, can be considered to be an enjoyable leisure time activity that is age appropriate for these children. However, it is also an educational tool that can directly address one of their major core difficulties, social interaction. These preliminary results are encouraging in light of the difficulty to find interventions that will both be enjoyable for children with ASD and will encourage them to improve their social abilities.

Future work will focus on a deeper quantitative and qualitative analysis of interaction, using the data provided by the log files of the application and through behavioural observation scales focusing on the assessment of collaborative and social abilities.

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Virtual human patients for training of clinical interview and communication skills

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ABSTRACT

Although schools commonly make use of standardized patients to teach interview skills, the diversity of the scenarios standardized patients can characterize is limited by availability of human actors. Virtual Human Agent technology has evolved to a point where researchers may begin developing mental health applications that make use of virtual reality patients. The work presented here is a preliminary attempt at what we believe to be a large application area. Herein we describe an ongoing study of our virtual patients. We present an approach that allows novice mental health clinicians to conduct an interview with virtual character that emulates 1) an adolescent male with conduct disorder; and 2) an adolescent female who has recently been physically traumatized.

1. INTRODUCTION

Although there are a number of perspectives on what constitutes trauma exposure in children and adolescents, there is a general consensus amongst clinicians and researchers that this is a substantial social problem. The effects of trauma exposure manifest themselves in a wide range of symptoms: anxiety, post-traumatic stress disorder, fear, and various behavior problems. Trauma exposure is associated with increased risk of psychological problems in adulthood. Effective interview skills are a core competency for the clinicians who will be working with children and adolescents exposed to trauma.

Developing effective interviewing skills for the clinicians, residents and psychotherapists who will be working with children and adolescents exposed to trauma is a necessary skill. A clinician needs to ask various questions relating to the trauma and its effect to properly assess the patient's condition. Current therapeutic training systems resort to using real persons (hired actors or resident students) acting as standardized patients to portray patients with a given mental health problem in what is called an Objective Structured Clinical Examination (OSCE). The problem portrayed by the actor could be physical or psychological. Although schools commonly make use of standardized patients to teach interview skills, the diversity of the scenarios standardized patients can characterize is limited by availability of human actors and their skills. This is an even greater problem when the actor needs to be an adolescent. The potential of using computer generated virtual humans as standardized virtual patients (VPs) for use in clinical assessments, interviewing and diagnosis training is becoming recognized as the technology advances (Bernard et al., 2006; Bickmore, Pfeifer, & Paasche-Orlow, 2007). These VPs are embodied interactive agents who are designed to simulate a particular clinical presentation of a patient with a high degree of consistency and realism (Kenny et al., 2007). VPs have commonly been used to teach bedside competencies of bioethics, basic patient communication, interactive conversations, history taking, and clinical decision making (Bickmore, & Giorgino, 2006).VPs can provide valid, reliable, and applicable representations of live patients (Triola et al., 2006). Research into the use of VPs in psychotherapy training is in its nascent stages (Johnson et al., 2007; Parsons et al., 2008). Since virtual humans and virtual environments can allow for precise presentation and control of conversations and interactions, they can provide ecologically valid assessments that combine the control and rigor of laboratory measures with a verisimilitude that reflects real life situations.

The current project aims to improve child and adolescent psychiatry residents, and medical students' interview skills and diagnostic acumen through practice with a female adolescent virtual human with post-traumatic stress disorder (PTSD). This interaction with a virtual patient provides a context where immediate

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feedback can be provided regarding trainees' interviewing skills in terms of psychiatric knowledge, sensitivity, and effectiveness. Use of a natural language-capable virtual character is beneficial in providing trainees with exposure to psychiatric diagnoses (e.g. PTSD), prevalent in their live patient populations, and believed to be under-diagnosed due to difficulty in eliciting pertinent information. Virtual reality patient paradigms, therefore, will provide a unique and important format in which to teach and refine trainees' interview skills and psychiatric knowledge. In order to be effective, virtual humans must be able to interact in a 3D virtual world, must have the ability to react to dialogues with human-like emotions, and be able to converse in a realistic manner. The combination of these capabilities allows them to serve as unique training tools whose special knowledge and reactions can be continually fed back to trainees. The goal of this virtual patient was to focus on a character with PTSD, our previous effort was on a character with Conduct Disorder. The eventual goal is to build a library of characters with a variety of psychiatric diagnoses to train residents and students at multiple levels.

Virtual Patients (VPs) are embodied interactive characters (Cassell, 1998) which are designed to simulate a particular clinical presentation of a human patient with a high degree of consistency and realism (Stevens, 2005) There is a growing field of applying virtual reality and virtual patients to issues such as therapy, telehealth, rehabilitation, training and prevention (Rizzo, 2006). VPs have commonly been used to teach bedside competencies of bioethics, basic patient communication, interactive conversations, history taking, and clinical decision making. (Bickmore 2006), (Bickmore, Giorgino, 2006), (Lok, 2006)

Results suggest that VPs can provide valid, reliable, and applicable representations of live patients (Andrew, 2006), (Triola, 2006). Virtual patients enable a precise presentation and control of dynamic perceptual stimuli (visual, auditory, olfactory, gustatory, ambulatory, and haptic conditions), along with conversational dialog and interactions, they can provide ecologically valid assessments that combine the veridical control and rigor of laboratory measures with a verisimilitude that reflects real life situations (Johnsen, 2007), (Parsons, 2007). As a result, VPs provide a reliable testbed from which to perform experiments and better understand the intricacies needed to effectively design and develop the underlying technology. Further, a great deal of work has been accomplished in constructing virtual human technology that allows these characters to implement an extensive array of interactivity (Hubal, 2004).

Building virtual humans to be used as patients requires a large integrated effort with many components. These patients are 3D computer generated characters that act, think and look like real humans. The users can interact with them through multi-modal interfaces such as speech and vision. The components in the system together form the body, the brain and the environment that the virtual humans exist in. The VP system is based on our existing virtual human architecture previously presented at I/ITSEC 2007 (Kenny,2007). The general architecture supports a wide range of virtual humans from simple question/answering to more complex ones that contain cognitive and emotional models with goal oriented behavior. The architecture is a modular distributed system with many components that communicate by message passing. Because the architecture is modular it is easy to add, replace or combine components as needed.

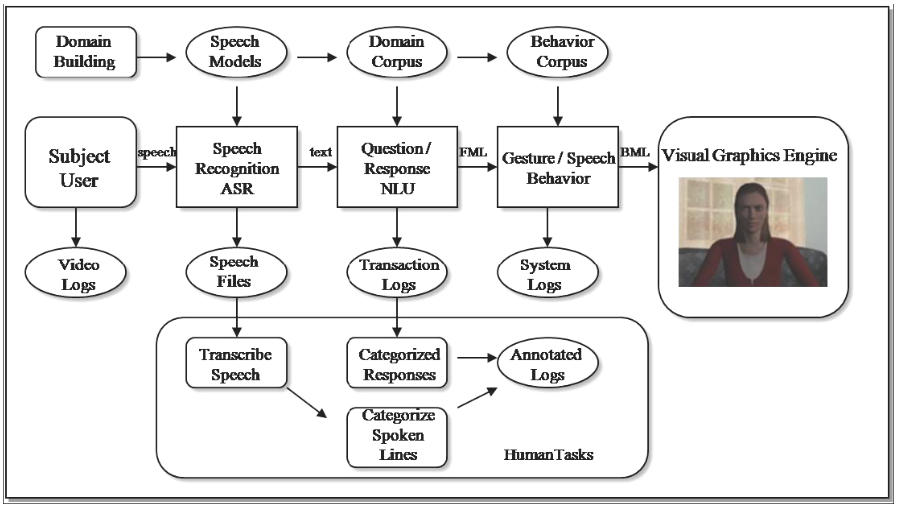

Figure 1. *Diagram Describing a Participant's Interaction with the System.*

Interaction with the system works as follows and can be seen in Figure 1. A user talks into a microphone that records the audio signal which is sent to a speech recognition engine. The speech engine converts the signal into text. The text is sent to a statistical question/response selection module. This module picks an

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appropriate verbal response based on the input text question. The selected response is then sent to a nonverbal behavior generator that selects output gestures, based on a set of rules. That gesture output is combined with the output text to be spoken, pre recorded or a computer generated voice, and played through an animation system which synchronizes the gestures, speech and lip syncing for the final output to the screen. The user then listens to the response and asks more questions to the character in an iterative process. Data is logged at each step to help with the evaluation of the technology. We have built two virtual patient characters with this system, but each has different domains. Justin, Figure 2, is an adolescent boy that has conduct disorder (Kenny 2007) and Justina, Figure 3, is a female assault victim character that has PTSD (Parsons 2008).

Figure 2. *Justin Virtual Patient.*

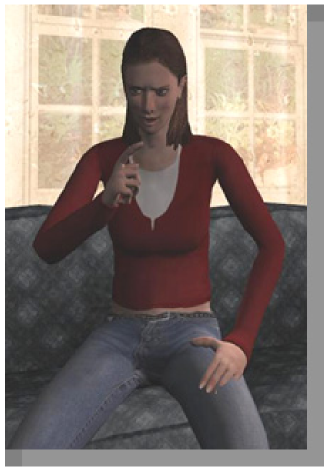

Figure 3. *Justina Virtual Patient.*

In this paper we present some virtual standardized patient characters that we have designed and developed in our lab. We also describe a series of studies in which we have made use of the virtual patient system for interactions with medical students. The results report the subject testing findings and in the discussion we evaluate the usefulness and effectiveness of virtual standardized patients as a medium to communicate with students, along with an evaluation of the system technology as a whole. We will also address several of the challenges in building virtual standardized patients and layout some of the research issues. We conclude with future directions in this domain and the ways in which virtual standardized patents may be applied to the training of future clinicians.

2. RESEARCH ISSUES IN VIRTUAL PATIENTS

There are many research areas in developing virtual humans and virtual patient technology such as speech recognition, verbal and non-verbal behavior, autonomous agents and tools to build the domains. This research is best done in an iterative process with subject testing to help inform the development and identify the problem areas. The main research areas can be broken down into the following categories:

2.1 Speech Recognition

The user has to interact with the system in some fashion. There are several ways this is commonly done; with a pull-down menu interface with scripted choices or with a speech or text interface for more natural interactions. With pull down or scripted interfaces, there are challenges in developing the set of items the user can choose. With a speech interface, where the input is more unconstrained, it is difficult to parse what the user says as speech technology is not 100% accurate. However in limited domains they can still function properly enough. The benefit is that it creates a much more natural interface for the user to interact with the virtual patient as they would with real patients. The drawback is that users tend to think of the technology as working at capacity and don’t understand when it does not perform well. There are two major research areas in speech recognition (Narayanan, 2004), proper recognition of voices, the speech model, and the size of the lexicon of words, the language model. Proper speech processing requires understanding the voice from people of all genders, ages and cultures. There is a trade off between having a general speech model that will recognize most voices, but have lower accuracy vs. a specific one, i.e. male or female, that will be better for that specific gender, but needs to be switched for different users. There is also a trade off between the accuracy of words recognized in the language model and the speed the database can be searched to figure out a correct response. It takes several weeks to build and train speech models and deciding on the proper words for the domain of interest to be put into the language models. This is best done in an iterative process.

2.2 Natural Language Dialog

Interactive characters need to engage the user in a realistic conversation. One important aspect of this engagement is the dialog that the subjects and the characters use, both on what they hear, or interpret what they hear, and what they say. There has been much work on natural language understanding and generation for characters (Traum 2007); however it is still a hard problem. One method that seems to work well is a statistical approach (Leuski, 2006), where a corpus of dialog for likely questions and appropriate responses is built. The input questions are matched with output responses by a user when building the dialog, and the system statistical picks the best one during run-time. It is still a challenge to build the dialog corpus for the domain and authoring tools are desperately needed.

2.3 Non-Verbal Behavior

Along with the verbal output of the character is the non-verbal behavior. This behavior consists of all the actions, animations, facial expressions, gaze and movements that the character will perform during the dialog exchange. The output gestures all need to be synchronized together with the dialog otherwise the timing will not properly match and it will look unnatural. This non-verbal behavior is difficult to design for virtual patients, because some of the actions that patients with mental health conditions perform may not be natural or normal, for example a muscle or eye tick or looking away for no apparent reason. To generate the non-verbal behavior output in our system is a two phase process. The first phase parses the output text and applies some rules to select animations, for example when the character says; "I don't know", an animation that points at itself is selected. (Lee, 2006) These rules can be designed by the user to match the desired condition. The second phase is synchronizing the selected animations, the output speech, and lip synching of the text for the character, this is done by a procedural animation system developed called Smartbody (Thiebaux, 2008)

2.4 Autonomous Agents

The virtual patient characters should act like real people with real mental conditions. This means they should have their own intrinsic behavior and remember past dialogs or subject areas talked about. They should be able to follow the conversation and add input or behavior on their own with initiative, emotion and personality. (Gratch, 2002) They current virtual patient system does not have an autonomous agent driving the underlying behavior, the behavior and dialog are driven by the input question. While this is effective, it does not create depth to the character. Developing agents with cognitive models and parameterized behaviors is a good foundational research area. As the mental conditions are better understood, deeper levels of cognitive models can be applied to the characters to give them rich behavior.

2.5 Domain Building and Tools

One of the challenges of building interactive VPs that can act as simulated patients has been in enabling the characters to act and carry on a dialog and behavior like a real patient that has the specific mental condition for the domain of interest. This dialog and behavior has to be inputted into the system and this can be a challenge for non-technical people. The process of knowledge acquisition and knowledge design is still a challenge as it requires breadth and depth of expertise in the psychological domain to gather the relevant material for the character and is usually constrained by the underlying technology. Tools to acquire the knowledge and build the domains and still in their infancy and need to be user friendly.

3. THE PTSD DOMAIN

This current virtual patient project aims to improve the interview skills and diagnostic acumen of psychiatry residents, military leaders and medical students. This is accomplished through interactions with VPs with various signs and symptoms indicative of a given mental health classification. Subjects interview a male patient with conduct disorder, or a female adolescent virtual human with post-traumatic stress disorder (PTSD). The interaction with a VP provides a context where immediate feedback can be provided regarding the trainees' interviewing skills in terms of psychiatric knowledge, sensitivity, and effectiveness. Use of an embodied natural language-capable virtual character is beneficial in providing trainees with exposure to psychiatric diagnoses such as PTSD that is prevalent in their live patient populations and believed to be underdiagnosed due to difficulty in eliciting pertinent information. Virtual reality patient paradigms, therefore, will provide a unique and important format in which to teach and refine trainees' interview skills and psychiatric knowledge. Additionally there is a growing need in the current military setting for training leaders to recognize signs of mental problems from returning veterans.

In our first attempt to design a VP 'Justin', Figure 3, we choose conduct disorder as the domain of interest, in which the patient's responses were reflective of someone that would be somewhat resistant to answering questions. Inappropriate or out of domain responses were seen as part of the disorder and this did not negatively impact the interview process. The current domain of PTSD is less forgiving and requires the system to respond appropriately based on certain criteria for PTSD. For the PTSD domain we built an adolescent girl character called Justina, see Figure 2. Justina has been the victim of an assault and shows signs of PTSD.

Although there are a number of perspectives on what constitutes trauma exposure in children and adolescents, there is a general consensus amongst clinicians and researchers that this is a substantial social problem (Resick, 1997). The effects of trauma exposure manifest themselves in a wide range of symptoms: anxiety, post-trauma stress, fear, and various behavior problems. New clinicians need to come up to speed on how to interact, diagnose and treat this trauma. One of the challenges of building complex interactive VPs that can act as simulated patients has been in enabling the characters to act and carry on a dialog like a real patient with the specific mental issues present for that condition in the domain of interest. The domain of PTSD requires the system to respond appropriately based on certain criteria for PTSD as described in the DSM manual (309.81; DSM American Psychiatric Association, 2000). PTSD is divided into six major categories as described in the DSM-IV:

A. Past experience of a traumatic event and the response to the event.

B. Re-experiencing of the event with dreams, flashbacks and exposure to cues.

C. Persistent avoidance of trauma-related stimuli: thoughts, feelings, activities or places, and general numbing such as low affect and no sense of a future.

D. Persistent symptoms of anxiety or increased arousal such as hyper vigilance or jumpy, irritability, sleep difficulties or can't concentrate.

E. Duration of the disturbance, how long have they been experiencing this.

F. Effects on their life such as clinically significant distress or impairment in social or educational functioning or changes in mental states.

Diagnostic criteria for PTSD includes a history of exposure to a traumatic event in category A and meeting two criteria and symptoms from each B, C, and D. The duration of E is usually greater than one month and the effects on F can vary based on severity of the trauma. Effective interviewing skills are a core competency for the clinicians, residents and developing psychotherapists who will be working with children and adolescents exposed to trauma. Rather than assessing for all of the specific criteria, we focused upon the major clusters of symptoms following a traumatic event. Next, we developed two additional categories that we felt would aid in assessing user questions and VP responses that are not included in the DSM:

G. A general category meant to cover questions regarding establishing rapport, establishing relations, clarifications, opening and closing dialog.

H. Another category to cover accidental mouse presses with no text, the user is required to press the mouse button while talking.

4. SUBJECT TESTING

We conducted subject testing of the Justin and Justina characters. Justin was a pilot test to assess the feasibility of the system, while Justina was a more indepth assessment of the dialog and interaction. This paper will concentrate on Justina, results from Justin can be found here (Kenny, 2007). Participants were asked to take part in a study of novice clinicians interacting with a VP system. They were not told what kind of condition the VP had if any. Two recruitment methods were used: poster advertisements on the university medical campus; and email advertisement and classroom recruitment to students and staff. A total of 15 people (6 females, 9 males; mean age = 29.80, SD 3.67) took part in the study. Ethnicity distribution was as follows: Caucasian = 67%; Indian = 13%; and Asian = 20%. The subject pool was made up of three groups: 1) Medical students (N=7); 2) Psychiatry Residents (N=4); 3) Psychiatry Fellows (N=4). For participation in the study, students were able to forgo certain medical round times.

4.1 Measures

Virtual Patient Pre-Questionnaire. This scale was developed to establish basic competence for interaction with a virtual character that is intended to be presented as one with PTSD, although no mention of PTSD is on the test.

Justina Pre-questionnaire. We developed this scale to gather basic demographics and ask questions related to the user's openness to the environment and virtual reality user's perception of the technology and how well they think the performance will be. There were 5 questions regarding the technology and how well they thought they might perform with the agent.

Justina Post-questionnaire. We developed this scale to survey the user's perceptions related to their experience of the virtual environment in general and experience interacting with the virtual character in particular the patient in terms of its condition, verbal and non-verbal behavior and how well the system understood them and if they could express what they wanted to the patient. Additionally there were questions on the interaction and if they found it frustrating or satisfying. There were 25 questions for this form.

4.2 Procedures

For the PTSD domain we used Justina, who has been the victim of an assault. The technology used for the system is based on the virtual human technology developed at USC (Kenny et al., 2007; Swartout et al., 2006). The data in the system was logged at various points to be processed later. Figure 1 is a diagram of how the user interacts with the VP system, described earlier, and the data logging and annotation pipeline. There are four areas where the data is logged. 1) The user speech is recorded from what s/he says; this lets us transcribe what the speech engine processes. 2) A transcript of the entire dialog session is recorded from the question/response system is saved. 3) System logs are stored to allow us to reconstruct what happened in the system if needed. 4) Cameras recorded participant's facial expressions and system interaction with the patient to be analyzed at a later time. The set of questions from the user and responses from Justina in the dialog interaction were classified into one of the DSM categories from above. This allowed us to study the responses of the system to questions asked by the subjects to see if they covered all the DSM categories.

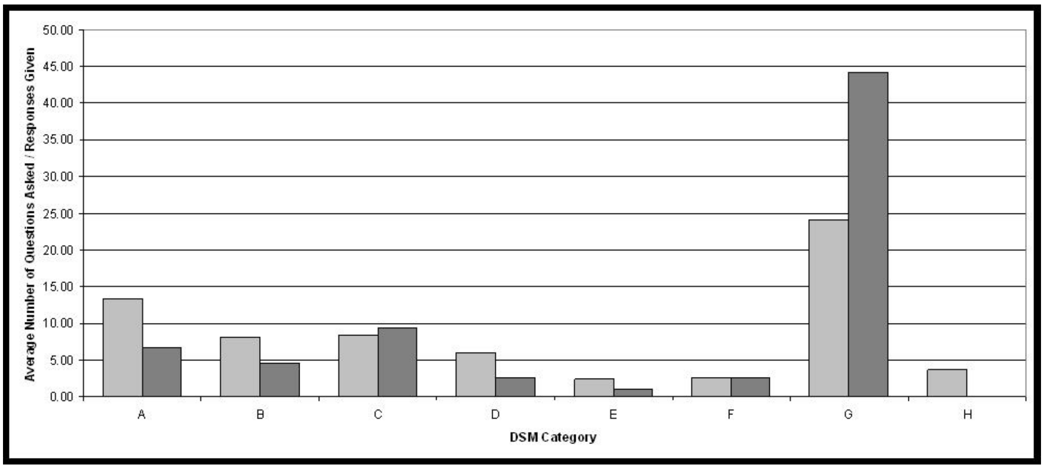

Figure 4. *Categorized Questions/Responses.*

5. RESULTS

Assessment of the system was completed with the data gathered from the log files in addition to the questionnaires. The log files were used to evaluate the number and types of questions that the subjects were asking, along with a measure to see if the system was responding appropriately to the questions. For a 15 minute interview the participants asked on average, 68.6 questions with the minimum being 45 and the maximum being 91. Figure 4 is a graph showing the average number of questions, asked by the subjects, lighter color, and responses by the system, darker color for each of the 8 DSM categories. It is interesting to note that most of the questions asked were either general questions (Category #G, Average 24 questions) or questions about the Trauma (Category #A, Average 13 questions), followed by category #C and #B, 8. The larger number of questions asked in #G was partially due to clarification questions, however we did not break down the category further to try to classify this. The distribution of questions in each category for each participant was roughly equivalent, which meant in general people asked the same kinds of questions There are several areas in the system that can be problematic due to technological issues which would cause the system to mis-recognize the question as out of domain, something the natural language system did not know about, and generate an inappropriate response. One such area was speech recognition. We used a speaker independent speech recognizer that did not contain all of the words or phrases asked by the subjects, as it was not known all the questions they would ask. Additionally the system did not perform as well for women voices as with men. The natural language system deals with out of domain questions by responding with an off topic response, in our case the phrase 'I don't get what you mean'. This was a particular issue, based on the questionnaires, where the subjects got frustrated, as the system responded with this phrase too many times and there was not enough variability with out of domain responses. This response was said in total 411 times across all subjects, comparing that to the total responses of, 1066, the ratio was one in every 2.5 responses. While there is no standard for a reasonable set of questions to out of domain responses, this ratio at least gives us a measure as to how well the system was performing. While this value may seem high and did frustrate some subjects, most subjects were able to continue with questioning and get appropriate responses to perform a diagnosis.

Future analysis on the speech recognition word error rate and accuracy will yield data as to what words and questions are needed to improve the speech models. It is clear from the transcriptions that the domain we built was not sufficient to capture all of the questions people were asking, the results from this study will be added to the domain for future testing. The interviewing method that people used to ask questions varied by individual; there were many different styles and personality factors that influenced the length and type of question, for example some people asked multiple segment questions, like 'hi how are you, why did you come here today?'. This is hard to recognize by the system, as it does not have natural language understanding. There are many novice assumptions by the subjects in how well this technology performs.

From the post questionnaires on a 7 point likert scale, the average value subjects rated the believability of the system to be 4.5. Subjects were also able to understand the patient, 5.1. People rated the system at 5.3 as frustrating to talk to, due to speech recognition problems, out of domain questions or inappropriate responses. However most of the participants left favorable comments that they thought this technology will be useful, they enjoyed the experience and trying different ways to talk to the character and also trying to get an emotional response for a difficult question. When the patient responded back appropriately to a question they found that very satisfying.

6. CONCLUSIONS

The primary goal in this study was evaluative: can a virtual standardized patient generate responses that elicit user questions relevant for PTSD categorization? Findings suggest that the interactions between novice clinicians and the VP resulted in a compatible dialectic in terms of rapport (Category G), discussion of the traumatic event (Category A), and the experience of intrusive recollections (Category B). Further, there appears to be a pretty good amount of discussion related to the issue of avoidance (Category C). These results comport well with what one may expect from the VP (Justina) system. Much of the focus was upon developing a lexicon that, at minimum, emphasized a VP that had recently experienced a traumatic event (Category A) and was attempting to avoid (Category B) experienced that my lead to intrusive recollections (Category C). However, the interaction is not very strong when one turns to the issue of hyper-arousal (Category D) and impact on social life (Category F). While the issue of impact on social life (Category F) may simply reflect that we wanted to limit each question/response relation to only one category (hence, it may have been assigned to avoidance instead of social functioning), the lack of questions and responses related to hyper-arousal and duration of the illness (Category E) reflects a potential limitation in the system lexicon. These areas are not necessarily negatives for the system as a whole. Instead, they should be viewed as potential deficits in the systems lexicon.

A secondary goal was to investigate the impact of psychological variables upon the VP Question/Response composites and the genreal believability of the system. After controlling for the effects of these psychological variables, increased effects were found for discussion of the traumatic event (Category A), avoidance (Category C), hyper-arousal (Category D), and impact on social life (Category F). Further, the impact of psychological characteristics revealed strong effects upon presence and believability. These findings are consistent with other findings suggesting that hypnotizability, as defined by the applied measures, appears moderate user reaction. Future studies should make use of physiological data correlated with measures of immersion to augment and quantify the effects of virtual human scenarios.

Herein we described an ongoing study of our Virtual Patient System. We presented an approach that allows novice mental health clinicians to conduct an interview with a virtual character that emulates an adolescent female with trauma exposure. The work presented here builds on previous initial pilot testing of virtual patients and is a more rigorous attempt to understand how to build and use virtual humans as virtual patients and the many issues involved in building domains, speech and language models and working with domain experts. The lessons learned here can be applied across any domain that needs to build large integrated systems for virtual humans. We believe this is a large and needed application area, but it's a small enough domain that we can perform some serious evaluations on using virtual humans in real settings.

We will continue to perform more rigorous subject testing with both professional medical students and with non experts to evaluate how well the different populations perform in the types of questions asked. Additionally further studies in comparing to real OSCE's with real actors to the virtual patient will be performed. Additional incorporation of rapport [7,12] using the facial gestures analysis with the system will further enhance the virtual patient interaction to produce more results in this domain.

Additional analyses that need to be performed with the data include: investigate the domains questions and responses to assess how many were on-topic and how many off topic; How well did the speech recognition perform based on word error rate; How did the speech recognition, graphics and non-verbal impact the subjects, their interview experience, presence and immersion in the system?; Can we automate the process of extracting data from large corpus of speech data in this domain to build topic areas?; Can we automate the process of classifying the subjects questions into the DSM categories from the speech or transcriptions of the speech? Define further sub-categories for interactive conversions, such as; opening, closing, empathy, topic area, follow-up, query, clarification, self-disclosure to name a few and annotate the transcriptions with these categories. This will help us to build better tools to build domains and characters.

It is our belief that with more questions covered in the domain the accuracy of the system will go up along with the depth of the conversions which will further enhance the virtual patient system. In order to be effective virtual humans must be able to interact in a 3D virtual world, must have the ability to react to dialogues with human-like emotions, and be able to converse in a realistic manner with behaviors and facial expressions. The combination of these capabilities allows them to serve as unique training and learning tools whose special knowledge and reactions can be continually fed back to trainees. Our initial goal of this study was to focus on a VP with PTSD, but a similar strategy could be applied to teaching a broad variety of psychiatric diagnoses to trainees at every level from medical students, to psychiatry residents, to child and adolescent psychiatry residents.

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Tele-evaluation and intervention among adolescents with handwriting difficulties – Computerized Penmanship Evaluation Tool (ComPET) implementation

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ABSTRACT

Writing is a complex and essential human activity. During adolescence, there is an increase in the complexity and quantity of writing required for communication, self-expression, and for demonstrating academic ability. Deficits in handwriting performance limit the writing abilities, and hence the participation of adolescents in many areas of life. Computer-based tele-rehabilitation has the potential to address handwriting assessment and treatment. The goal of the present study is to examine the potential of the ComPET as a tool to assess and treat adolescents with handwriting difficulties. A case report is presented.

1. INTRODUCTION

1.1 Handwriting

Writing is indispensable for participation in school activities. As their schooling progresses, students are expected to cope with more difficult tasks, to demonstrate their knowledge understanding on a progressively higher level, and to integrate the material they have previously studied (Graham, Berninger, Weintraub, & Schafer, 1998). The demands for written work increase dramatically during the middle and secondary school years (Weintraub, Drory-Asayag, Dekel, Jokobovits, & Parush, 2007). No other school task requires as much synchronization of abilities as does handwriting (Levin, Oberklaid, & Meltzer, 1981). It follows that this complex occupational task demands the integration of many underlying component skills, which if lacking, may interfere with handwriting performance (Feder & Majnemer, 2007). Deficits in handwriting performance limit the school participation of adolescents, negatively affect students' grades (Christensen, 2005), self esteem, motivation for studying and social interaction (Sassoon, Nimmo-Smith, & Wing, 1986).

To date, most of the theoretical and research knowledge in the area of handwriting relates to elementary school students (Graham & Weintraub, 1996). Graham and Perin (2007) state that writing in general, and teaching writing skills to struggling adolescent learners in particular, has not received enough attention by researchers and educators. They point out that we cannot assume that instructional strategies and approaches validated with younger struggling writers are equally effective for students in the middle and upper grades. A meta-analysis conducted by Graham and Perin (2007) indicates the need to perform a careful evaluation of a teenager's handwriting performance, through both formal and informal methods, before choosing the appropriate remediation approach. The instruments chosen should best match the adolescent's areas of handwriting difficulty so as to facilitate the implementation of an effective treatment strategy. A quantitative scoring system is critical in identifying the problem areas to be targeted during remediation, in monitoring a client's progress after intervention, and in communicating the results more clearly (Feder & Majnemer, 2007).

It is understood that privacy, accessibility and anonymity considerations are very important when planning intervention with adolescents (Barak, 2006). However, the capacity to provide effective evaluation and treatment to adolescents with writing difficulties may be limited by difficulties experienced in accessing occupational therapy services. Such difficulties may arise because of the distance involved in commuting to service locations, financial limitations and institutional prioritization of cases. Tele-rehabilitation, a service delivery model in which rehabilitation services are provided at a distance, using information and communication technology, may offer an alternative or adjunct service delivery model to facilitate or enhance access to service for adolescents who are struggling with writing difficulties (Torsney, 2003).

1.2 Computerized Handwriting Process Evaluation

Technology enables the analysis and precise assessment of the writing process and product (Wann & Kardirkamanathan, 1991). The development of the digitizer (Rosenblum, Parush, & Weiss., 2003) enables the measurement of a rich variety of spatial, pressure, and temporal measures by a computerized system (ComPET) (see Rosenblum, Parush, & Weiss, 2003). The Computerized Penmanship Evaluation Tool (ComPET, previously referred to as POET; Rosenblum, Parush, & Weiss, 2003) is a standardized validated handwriting assessment that utilizes a digitizing tablet and on-line data collection and analysis software. It was developed for the purpose of collecting objective measures of the handwriting process (for more details see: Rosenblum et al., 2003; Rosenblum, Chevion, & Weiss, 2006; Rosenblum & Livneh-Zirinski, 2008),

The tasks are performed on A4-sized lined paper affixed to the surface of a WACOM Intuos II *x-y* digitizing tablet (404 x 306 x 10mm), using a wireless electronic pen with a pressure-sensitive tip (Model GP-110). This pen is similar in size and weight to regular pens commonly used by adolescents and, as such, does not require a change in grip that might affect writing performance.

Displacement, pressure and pen tip angle are sampled at 100 Hz via a 1300 MHz Pentium computer.

It seemed likely that the use of the ComPET in the assessment and training of adolescents with handwriting difficulties might be an appropriate approach for their needs. For example, this approach eliminates the need for eye contact, neutralizes the bias of age status, and enables the creative use of coded language, drawings, symbols and interpersonal communication on a textual basis. These are just some of the features that make tele-rehabilitation advantageous and affordable through the use of the ComPET technology. These features might enable effective alternatives that address the special needs of this age group for growth, emotional maturation and for skill acquisition and learning. In addition, the unique features of this approach can help construct a positive and significantly attractive intervention program for youths.

The ComPET allows for greater flexibility in choosing appropriate tasks for the client. For example, tasks can be performed in any language and without regard for task length or time limits. To enable the choice of functional tasks that address each individual adolescent’s needs, an interview could be conducted prior to the initiation of treatment.

The case report that will present below will demonstrate these ideas.

Figure 1. *Computerized Penmanship evaluation Tool (ComPET).*

1.3 Tele-Rehabilitation

Home healthcare has assumed an increasingly important role in healthcare over the last 20 years. Occupational and physical therapy interventions that may be suitable for tele-rehabilitation include assessment of the home environment and training in adaptive strategies (Hoenig et al., 2006). In recent years, a number of studies have examined the use of computer-based tele-rehabilitation systems (Brennan, Georgeadis, Baron, & Barker, 2004; Hill et al., 2006; Mashima et al., 2003). As a result of the relatively low cost of installation and maintenance of computers, as well as their general availability, such systems may help to alleviate difficulties in accessing rehabilitation services.

It is also important to note that computer-based tele-rehabilitation provides the opportunity to focus on an individual's unique abilities and difficulties, thus enabling the development of a tailor-made intervention approach and the utilization of techniques that suit his or her specific needs. The flexibility derived from computer-based tele-rehabilitation may also allow for the use of established practices, such as the ability to deliver standardized assessment tools in an online capacity. For instance in Australia, the wide distribution of the population and increased use of technology in regional and remote areas support the use of computer-based tele-rehabilitation systems (Lloyd & Bill, 2004). The application of computer-based tele-rehabilitation is also supported within populations of people with disabilities. For tele-rehabilitation to be truly effective, researchers must establish valid and reliable assessments that can be performed from a distance. This requirement is important not only for initial assessment and diagnosis but also for ongoing monitoring and maintenance of client progress (Hill et al., 2006).

1.4 Method for Integrating the Use of the ComPET and Tele-Rehabilitation to Assess and Treat Adolescents with Handwriting Deficits

The main idea behind the development of the proposed method is to combine the opportunities offered by tele-rehabilitation and the ComPET, in order to provide an intervention program that can best fit the needs of adolescents with handwriting difficulties.

We propose the use of a multistage process. To begin, we send an invitation to participate in our research through internet forums targeting adolescents or adolescents' parents. We will state that we are looking for volunteers who might have handwriting problems and would be interested in attempting our novel approach. Respondents will be asked to share with us their experiences with writing assignments and the influence that writing problems have had on their lives.

Next, these adolescents will be mailed a questionnaire that focuses on their activities and degree of participation in daily life occupations (Kirby & Rosenblum, 2007). To complete the background data collection, an interview will be conducted with the participants though Skype, to solicit more detailed information regarding the typical environments which they occupy, as well as their daily life activities.

Based on the information received an individual ComPET.evaluation program will be set up.

1.4.1 Tasks and Apparatus. This research represents the first time the ComPET is to be used for treatment following the evaluation process. The plan is to choose tasks from an ecological perspective, such that they are familiar and common tasks that the individual routinely performs at school, relevant to client's context and that are based on information drawn from the questionnaire and from the Skype conversations. The tasks are to be written in Hebrew, a language in which the writing progresses from right to left. In Hebrew, successive letters are usually not connected, even in script or cursive writing and some letters are comprised of two separate, unconnected strokes.

1.4.2 ComPET Outcome Measures. The primary outcome measures are to be comprised of temporal, spatial and pressure measures for each writing stroke, as well as overall performance on the entire paragraph. The temporal measures will include 'on-paper' time (the time during writing performance in which the pen is in contact with the writing surface)and 'in-air' time (the time during writing performance in which the pen *is not* in contact with the writing surface) (Rosenblum, Parush, & Weiss (2003). The spatial measure will include the mean stroke height and width for each task. In addition, the ComPET computes the mean pressure applied to the paper, as measured in non-scaled units from 0 to 1024, as well as the mean pen tilt in the range of 0-90 degrees (i.e., the angle between the pen and its projection on the tablet).

1.4.3 Procedure and data analysis. As was described previously, the tasks will include a message on the internet's forum, the completion of a written questionnaire that is to be mailed to the adolescents that responded to our message and a Skype interview with each of them. This information will form the basis for the choice of the assessment writing tasks and their performance via the ComPET.

Once the findings from the evaluation and assessment sessions are examined, we will build an individually tailored intervention program, designed from a combination of intervention techniques suited for each of our client's needs. We will reassess the client's performance after each intervention session, so the client, and we, can follow his or her progress throughout the process.

The case report will illustrate the background data collection process and examples of data that can be derived through the use of the ComPET.

2. CASE REPORT

2.1 Personal Details

In a feasibility survey conducted to explore the potential viability of selecting participants via the internet, we sent a message to 10 internet forums that target adolescents or adolescents' parents, and asked for volunteers who might have writing problems and would be interested in participating in our novel research. Within 48 hours we received responses from 12 adolescents or their family members.

O.B., a 16 years-old Jewish boy, is one of the adolescents that replied to our message. O.B. is an Israeli born high school student who lives in the city. He informed us that he uses his right hand for writing and usually writes in Hebrew. His parents reported that he experiences difficulties with writing assignments, has illegible and dysfluent handwriting, and has great difficulty in completing his assignments on time.

Following O.B.'s reply, we mailed him a questionnaire focusing on his activities and degree of participation in daily life occupations (Kirby & Rosenblum, 2007). From his responses, we learned that he has difficulties with a variety of activities of daily life, such as in organizing his room, organizing the tasks he needs to do so that he can get to school on time and in spatial orientation. In addition, it was apparent that O.B. has difficulties in performing other complex motor activities, for example, riding a bike or playing music. To complete our background data collection, we conducted a Skype conversation with O.B. to solicit more detailed information regarding the typical environments which he occupies, as well as his daily life activities.

In O.B.'s case, because we suspected that his handwriting difficulties relate to his organizational problems, difficulty in preserving letter forms and motor problems, we chose a series of tasks in a graded progression. Initially, we started with automatic tasks, such as writing his name. Later, we gave him tasks requiring unrestricted writing, followed by tasks in which he was to copy short texts and then longer ones. He completed assessment tasks that were given without any time limitations. He was assessed in a 20 to 40-minute individual session at home. He was asked to sign his name five times, to write a paragraph about his activities during a typical day and to copy a short paragraph. Data were analyzed with the digitizer.

The Rey Complex figure, a standardized test for the evaluation of visuo-spatial organization was also performed on the digitizer and the temporal, spatial and pressure data of the performed task were analyzed by ComPET.

3. RESULTS

To demonstrate the advantages of the ComPET system, examples of some of O.B's evaluation results are presented below (left side) alongside comparative results of a matched control participant with proficient handwriting (right side). Presenting the results in this manner allows for the illustration of the ComPET's ability to both distinguish between poor and proficient handwriting, as well as to highlight the deficient components underlying his handwriting problems. This information then enables the development of an individually tailored intervention program most suitable to his needs.

In the following figures and tabular presentations of the results, temporal measures are recorded in seconds, spatial measures in centimeters and pressure measures in non scaled units ranges from 0-1024.

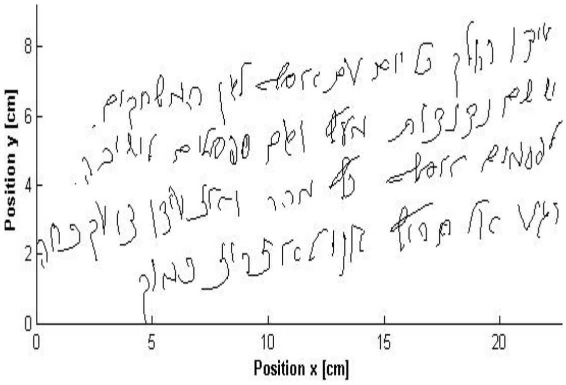

Figure 2A. *O.B. – paragraph copying.*

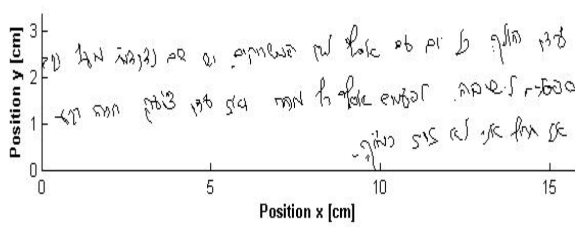

Figure 2B. *Proficient handwriter – paragraph copying.*

On the left side (Fig. 2), a short paragraph copied by O.B is presented. The handwriting product demonstrates several problems. Specifically, there is no clear difference in the spacing between letters and words (i.e., in Hebrew, a space of about one millimeter is required between each letter, while a space of about four millimeters is required between words. To illustrate the problem, some words are lined). Furthermore, some letters (marked by circles) are not readable, the sentences are markedly sloped and the organization of the writing product is not properly organized within the writing space.

Figure 3 (A&B) refers to the pen pressure applied by the pen to the writing surface during the performance of the paragraph copying. The X axis represents the pressure values, ranging in non scaled units from 0-1024; the Y axis represents the frequency of those values throughout the performance.

The graph reveals that during 70% of the writing performance time, O.B placed very high levels of pressure on his pen, while the skilled adolescent shows varied levels of pressure while writing.

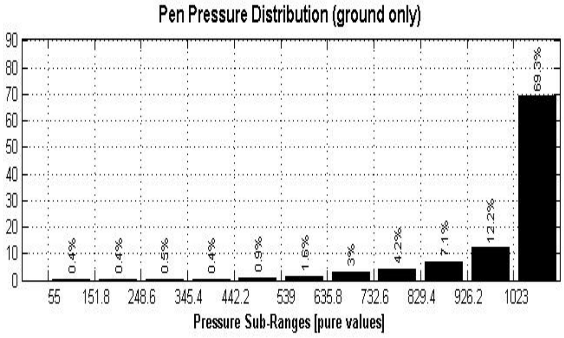

Figure 3A. *O.B. – pen pressure value distribution in the paragraph copying task.*

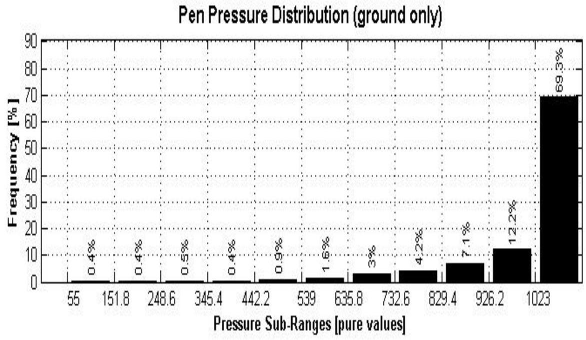

Figure 3B. *Proficient handwriter – pen pressure value distribution in the paragraph copying task*

As was previously mentioned, the data supplied by ComPET provides objective measures relating to handwriting performance. To illustrate, we have presented some examples of the data collected from the assessment of O.B. in comparison to data collected from an assessment of a proficient handwriter of the same age. 'On paper' refers to the time in which the pen is in contact with the paper, whereas 'in air' refers to the time in which the pen is not in contact with the paper (i.e., the time in which the pen is located in the air, such as between letters and words).

Table1. *Temporal measures, Velocity and Pen-pressure values obtained from O.B's paragraph copying task in comparison to those of a proficient handwriter.*

Measure	**O.B.**	**Proficient handwriter**
Overall duration of the writing task	116.74 sec.	40.24 sec.
Overall duration of the on paper strokes	68.83 sec.	19.11 sec.
Overall duration of the in-air strokes	45.97 sec.	18.73 sec.
Mean stroke duration	0.15 sec.	0.46 sec.
Mean velocity (cm per second)	3.93 sec.	3.42 sec.
Mean pen pressure	962.15	825.33

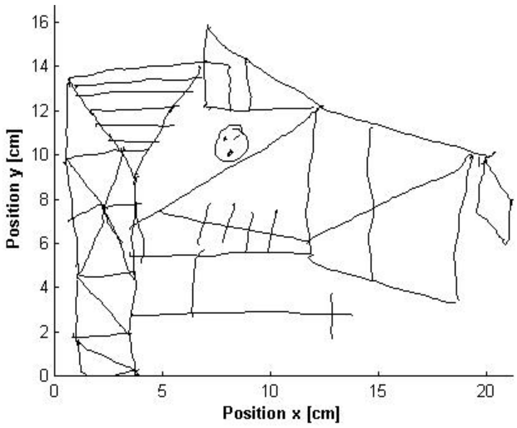

Figure 4A. *OB's performance of the modified Rey–Osterrieth Complex Figure.*

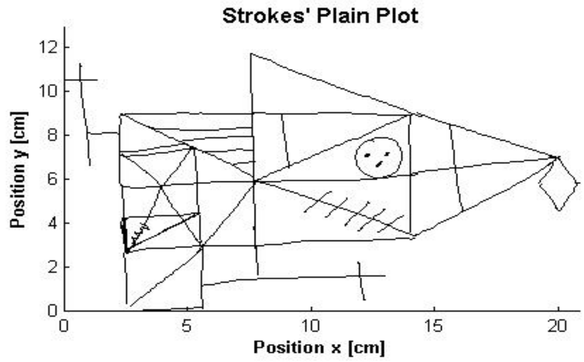

Figure 4B. *Proficient handwriter's performance of the modified Rey–Osterrieth Complex Figure.*

The two figures presented above illustrate the ability of the ComPET to demonstrate organizational problems. These figures also illustrate how one might combine the use of the findings of the Rey–Osterrieth Complex Figure tool with the measures of pen- pressure and velocity via the ComPET. The capability and flexibility provided by the use of the ComPET in combination with other assessment tools enables the therapist to identify deficiencies in handwriting performance and, in this way, helps the therapist design a suitable intervention program for the client.

4. DISCUSSION

The case report presented here supports our stated objective regarding the ComPET's potential as a tool to assess and treat adolescents with handwriting difficulties. Based on the information collected from the questionnaire and the interview, we were able to focus on O.B.'s special needs and to choose fitting tasks for his assessment. Similarly, we can use these methods to build an appropriate intervention program for him.

It was very important for us to learn that O.B enjoyed the process and appreciated that it could be accomplished in the privacy of his home and that his assignments were saved in a secure personalized area within a secure internet site that was not accessible to outsiders. In this way, he could review his work and monitor his progress throughout the process in an unthreatening manner.

Our future research will continue to examine the efficacy of the ComPET as a tool to assess and treat adolescents with handwriting difficulties. In addition, it will focus on developing optimal intervention methodologies through the use of the ComPET. As was mentioned previously, proficient handwriting requires the synchronization of a complex variety of underlying abilities and skills. Thus, handwriting intervention requires the therapist to perform a careful assessment and develop a tailored, individualized treatment program for each client.

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Gazing into a Second Life: gaze-driven adventures, control barriers, and the need for disability privacy in an online virtual world

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ABSTRACT

Online virtual worlds such as Second Life and World of Warcraft offer users the chance to participate in potentially limitless virtual worlds, all via a standard desktop pc, mouse and keyboard. This paper addresses some of the interaction barriers and privacy concerns that people with disabilities may encounter when using these worlds, and introduces an avatar Turing test that should be passed for worlds to be accessible for all users. The paper then focuses on the needs of high-level motor disabled users who may use gaze control as an input modality for computer interaction. A taxonomy and survey of interaction are introduced, and an experiment in gaze based interaction is conducted within these virtual worlds. The results of the survey highlight the barriers where people with disabilities cannot interact as efficiently as able-bodied users. Finally, the paper discusses methods for enabling gaze based interaction for high-level motor disabled users and calls for game designers to consider disabled users when designing game interfaces.

1. INTRODUCTION

Online virtual environments are becoming increasingly popular as a means of interacting, chatting and spending time with friends and new acquaintances. Second Life, Entropia Universe, World of Warcraft and so on are part of the growing family of Massively Multiplayer Online Games (MMOG) and as computers and the internet become faster these worlds become more realistic and immersive.

Within these communities the users are represented as a virtual projection of themselves in the form of an avatar. The user can choose to appear as any shape, size, colour or other appearance that the game customisation allows, with the interaction taking place in a 3-dimensional world. The level of personal disclosure is entirely up to the user.

Depending upon the aim of the game, users are free to move around by walking, running or even flying. Objects can be created from simple shapes to complex virtual homes and even moving objects such as cars or spaceships. As these worlds are virtual, then almost anything creative may be possible. An example of such a world can be seen in figure 1. The screenshot shows our view of the world from a third person perspective, with our avatars back to us and the camera placed behind the avatar. Much of the scene is animated, including the trees and plants that move in the virtual breeze; running water can be heard coming from a fountain to the left although it cannot be seen from the current viewpoint; video advertising boards advising us on where we should visit.

2. WHO IS ME? THE VIRTUAL APPEARANCE OF DISABILITY

As well as being fun and engaging, virtual worlds allow users to do many things that they may not be capable of doing in the real world. Users are offered an environment that allows them to overcome normal physical limitations and do almost anything, human, or super-human. It is these very attributes that are now offering new opportunities to users who may have a physical disability - just as an able-bodied person can do anything in a virtual world, so may a person with a disability. However, there are differences to consider. A person suffering from a high-level spinal injury may use a wheelchair in the real world, but in the virtual world they may choose not to. The choice to disclose the disability in their avatar's appearance is the prerogative of the individual (Harrigan, 2007). Merely, looking at the avatars in Second Life it appears that most users, regardless of disability, choose to project an over-stylised version of themselves rather than a 'close-as-possible' appearance. Thus the virtual world becomes a very powerful tool for liberation and levels the abilities of able-bodied and disabled users alike. Harrigan uses a blog to discuss her own experiences as a paraplegic taking part within a Second Life community group called Wheelies. The group creator Simon Stevens, who suffers from cerebral palsy, explains his thoughts on the appearance of disability:

> *"The avatar is a powerful device in ensuring an inner self-identity. So for some disabled people, Second Life is an opportunity to escape from their impairment. Disclosure is optional and this "second life" often suits people who became disabled after birth. There is, however, a group of disabled people, including myself, who wish to appear disabled within Second Life. Within an environment which is perceived to be barrier free, it challenges the very nature of impairment and disability when someone chooses to appear disabled."*
>
> *– Simon Stevens (Harrigan, 2007)*

Figure 1. *'Second Life' created by Linden Labs – www.secondlife.com.*

2.1 The Barrier of Control

The typical method of interaction in these environments is via a combination of mouse and keyboard; with the keyboard being used for navigation and text entry and the mouse for controlling the camera and application control. Consider the scenario of a disabled user with a high level of paralysis. What if they are unable to use a conventional mouse and keyboard yet wish to appear as able-bodied as any other user in the virtual world? They are now presented with a barrier of how they might control their avatar rapidly and effectively so as not to appear as if there are difficulties with computer control. Appearance is only one requirement of avatar realism. Even if the avatar appears able-bodied, it will be judged on how interactive and believable it behaves (Romano, 2005). An avatar being controlled by a disabled should have the option of being indistinguishable from the rest. This is reminiscent of an avatar Turing test (Turing, 1950) in which, whilst interacting with several able-bodied avatars, one of which is controlled by a disabled user, the test subject is unable to detect any difficulty that a user may have in computer control caused by a disability.

2.2 The Control Demands of a Virtual World

As virtual environments strive for more realism, the barrier of being able to control the appearance of online presence is becoming more critical for disabled users. The move to realism and feature-rich interaction can be seen if we examine four different 'chat' methods; *email*, *chat rooms*, *simple avatars* and *realistic avatars*. At the very basic level of *email* there is no time pressure that the user is faced with – they can take several hours, days or even weeks to respond. A *chat room* requires faster interaction from the user than is required for *email* but it is acceptable to have a few minutes in between responses. Second Life comes under the *simple avatar* category and requires real-time interaction in order to preserve privacy. Many users expect almost instant responses when chatting at this level and not to meet this demand can result in users becoming bored and questioning why the avatar is not responding like everyone else. Online virtual environments have

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already begun to move towards creating *realistic avatars*. In this category, avatars are able to verbally communicate using VoIP (Voice Over IP) technology. There are also possibilities for the avatar to respond to our facial expressions and body movements due to advancements in facial and gesture tracking. This hierarchy of an ever increasing communication burden on disabled users threatens their choice of disability privacy. Figure 2, highlights the increased difficulty as the demands of communication time (the latency of your response to a communication or action from another online person) and the amount of data that needs to be generated to enable complete communication or control over your online presence increases. It is this ever increasing control bandwidth that is giving rise to avatar realism that contributes to the increasing need for communication and control efficiency. Communication difficulties are further compounded due to the interfaces used in online virtual environment and the fact that they are not designed to aid disabled users.

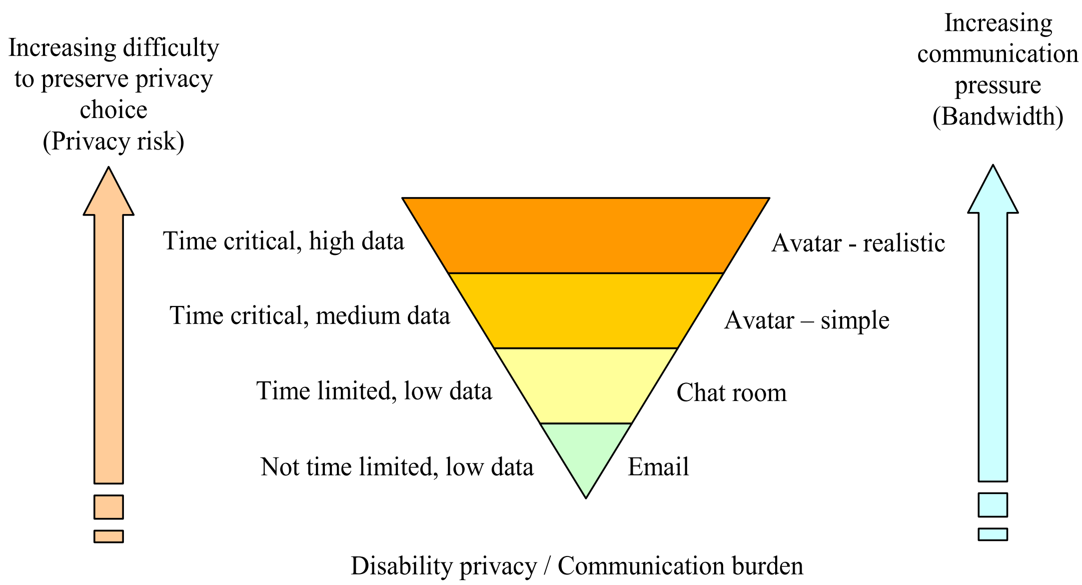

Figure 2. *Disability privacy burden by online meeting type (Bates et al, 2008).*

3. INTERACTION IN SECOND LIFE

To survey interaction and the burden of control in Second Life it was necessary to determine the main type of tasks that occur. Hand (Hand, 1997) previously proposed a taxonomy of main control and manipulation areas that are present in virtual environments: locomotion and camera movement; object manipulation; application control; communication (previously not specified by Hand):

- Locomotion and camera movement. These both may be controlled by using arrow buttons located on semi-transparent overlays as can be seen at the bottom of figure 1. Continuous motion is performed by holding the mouse button and performing a ‘dragging’ motion. There are also keyboard shortcuts to perform avatar movement by using the cursor arrow keys. In many online virtual environments there are also possibilities to use the ‘W, A, S and D’ keys to perform movements.
- Object manipulation. This is only achievable through mouse control. In order to manipulate an existing object then it is selected with a right mouse click, at which point a semi-transparent pie menu appears at the point of click, see bottom right of figure 1. The pie menu offers several options related to the object such as ‘Open’, ‘Edit’ and ‘Sit Here’. A new object is created by selecting the ‘Create’ option within the pie-menu. This causes a dialog box to appear offering basic functions similar to those found in 3D modelling packages.
- Application control. This is mostly accomplished using the mouse although there are several commands and menus accessible via the keyboard. Menus must be opened using left button mouse clicks and although some commands can be accessed using a keyboard the majority of the menu functions are available using mouse only. One of the major functions within Second Life is the changing of the avatars appearance and is only accessible through using a mouse, apart from keyboard tabbing between buttons and using arrow keys with slider controls.
- Communication – chatting and generating text (previously not specified by Hand). This is achieved through text generation or speech relay via a microphone. A chat box lies at the bottom left of the

screen, see figure 1, and text generated through conversation is displayed. Speech relay allows the voice of the user to be heard by nearby avatars, together with hearing any nearby avatars.

These control requirements can be summarised by control source and task domain, see table 1, and allows us to determine what control combinations are required to interact within Second Life.

Table 1. *Control requirements for task domains (Bates et al, 2008).*

	Control source		
Task domain	Mouse	Keyboard	Speech
Locomotion and camera movement	✓	✓	×
Object manipulation	✓	×	×
Application control	✓	Partial	×
Communication	×	✓	✓

3.1 Gaze Control

Users with severe motor disabilities cannot always operate a standard hand mouse or keyboard; and may have difficulties moving their head; they may have some speech but there may be problems with speech recognition die to aided respiration. In most cases however, these users would still retain eye movement since eye control is retained in all but the most advanced cases of paralysis, such as ALS (Amyotrophic Lateral Sclerosis).

Gaze tracking has been show as an effective means of computer control for users with high levels of paralysis (Bates, 2002; Bates and Istance, 2002; Bates and Istance, 2004) and has been used effectively for gaming (Smith and Graham, 2006; Isokoski, 2006; Dorr et al, 2007) and in immersive environments (Tanriverdi and Jacob, 2000; Cournia et al, 2003). One approach to using eye gaze is with mouse emulation by gaze tracking, where the system cursor follows the users point-of-gaze on the screen, and keyboard emulation via an on-screen keyboard. However, simply using the eye as a mouse has a number of problems (Vickers et al, 2008).

It is important to make an initial assessment of gaze based mouse emulation as a satisfactory solution for disabled users interacting with Second Life or similar environments. The assessment would determine if this alternative means of interaction would enable successful, rapid, effective and hence efficient interaction with Second Life by giving users full control over their avatar, whilst not revealing their disability.

4. AN EXPERIMENT

In this initial assessment two expert users of eye tracking and Second Life were chosen to attempt gaze control with the online environment. The issue was not to conduct an in depth study but to simply assess the feasibility of using eye gaze. As a baseline, the participants also interacted with the environment using a normal desktop mouse. Five tasks were constructed from the essential task domains as discussed previously, table 1, of which the avatar was required to perform a short set of actions. The participants were sat approximately 60cm from a 17″ monitor, with the SMI REDII remote infrared eye tracker giving an approximate accuracy of +/- 0,5 to 1cm in cursor position on the screen. The tasks were as follows:

- Locomotion – the participant was required to walk the avatar along a path approximately 2 paces wide around a park, negotiating past trees and other distracting obstacles;
- Camera Movement – the participant was to move the camera from behind the avatar to face it, and then move overhead to view the avatar from above
- Object manipulation – the participant was to create a cube and resize to be as close to 2m cube as possible
- Application control – the participant was to change the appearance of the avatar by making the hair colour blonde
- Communication – the participant was to chat with another avatar, generating the following “The weather here is nice, it is always sunny and warm”.

Completion times together with the errors occurring during the task were recorded, and the subjects were asked to make comments on gaze controlled task areas they found easy or difficult. The average results can be seen in table 2.

Table 2. *Task times and error counts based on task domain*

	Control source; task time (s); error count	
Task domain	Mouse (baseline)	Gaze
Locomotion	48s (3 errors)	88s (4 errors)
Camera movement	50s	122s (10 errors)
Object manipulation	35s	71s (3 errors)
Application control	20s	194s (4 errors)
Communication	60s (11 wpm)	224s (8 errors, 3 wpm)

Four main types of difficulties were identified and were defined as follows:

- Path deviation – movement or wandering from the chosen or desired path made by poor positional control of the avatar direction;
- Distraction – errors particular to gaze control where the gaze is distracted to another object in the world and since gaze is controlling motion direction; that motion is also pulled toward the distraction;
- Accuracy – simple pointing accuracy problems due to the inaccuracy of gaze tracking and pointing resulting in difficulties placing the cursor on small controls;
- Feedback – the continued gazing between the interaction point where gaze is manipulating a control, and the location of the actions or feedback caused by manipulating that control.

We can now discuss the results and examine the effectiveness of gaze control against the baseline of the hand mouse for each of the task domains.

4.1 Locomotion

The major issue was of distraction, where the gaze of the user was pulled away, even temporarily, from the desired destination to some other in-world object, hence moving the avatar toward that object involuntarily. This is illustrated in a sequence (figure 3, left to right) where the gaze (shown as a red star) is distracted by a tree, resulting in the avatar walking into the tree instead of staying on the path.

Figure 3. *Locomotion and distraction.*

Examining the comments made by the evaluators, gaze driven locomotion was regarded as viable: “Steering by eye worked well, all I needed to do was to look at the object I wished to walk towards”, “I feel that this could be a very rapid means of steering, just look and you go right there, it could be better than a mouse”. However, the main issue of distraction was noted “You can’t look around while you are walking without walking off the path”.

4.2 Camera Movement

There were a large number of feedback errors caused by the difference in screen location between the camera control and the view of the avatar on the screen. This is illustrated in a sequence (figure 4, left to right) with continual gazes back and forth between the camera control and the avatar (to determine the new camera position) resulting in the camera tracking and responding to the movement of the cursor – note how the camera orientation rapidly moves between the user looking at the control (left and right images), and the user looking at the avatar (centre image).

Figure 4. *Camera movement and feedback.*

4.3 Object Manipulation

Of particular interest was when once the handles of the object were acquired, the object could be resized very effectively with gaze due to the appearance of rulers extending from the object, with the user simply needing to gaze at the required measurement (placing the cursor on that measurement) for the object to be correctly resized. This is shown where the user is gazing at 4m on the ruler thus resizing the object to 4m (Figure 5).

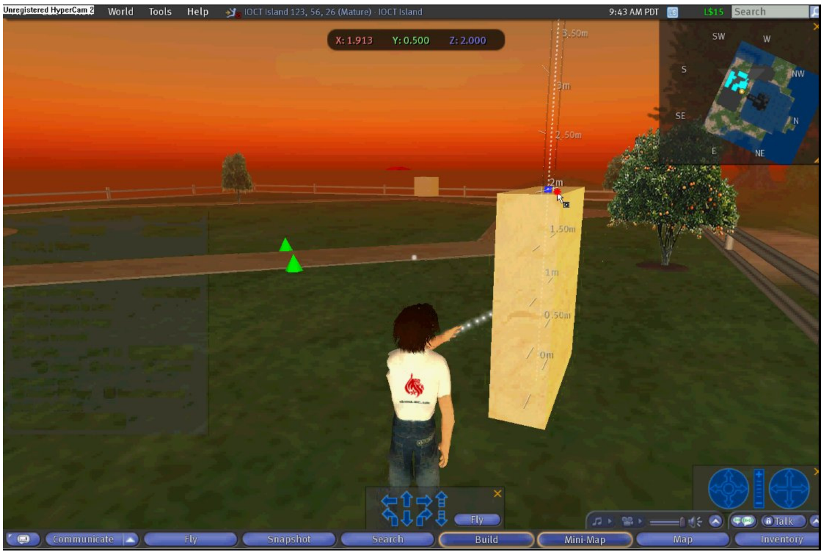

Figure 5. *Object sizing by gaze.*

4.4 Communication

The use of an on-screen virtual keyboard was slow for the mouse (11 words per minute) and very slow for gaze (3 words per minute), thus presenting a significant communication problem for our disabled user. This is illustrated by red lines (gaze paths) and red dots (gaze fixations) showing the many gazes between keyboard and chat box on Second Life when writing only 10 characters (figure 6).

Figure 6. *Feedback while gaze typing.*

5. CONCLUSIONS

The ideas, concepts and data presented in this paper form the basis for preliminary observations and are intended to indicate directions for research rather than to provide definitive answers. It is shown from the results and difficulties found that using eye gaze is constrained by the existing interfaces and will not deliver the bandwidth of interaction necessary to safeguard the privacy choices of disabled users. At present existing virtual world interfaces will almost always force the disabled user to not perform as well as more able users, and hence fail the avatar Turing test.

The types of difficulties found suggest a need for a lightweight 'gesture' mechanism (Istance et al, 2008; Vickers et al, 2008) whereby gaze control can be activated and deactivated quickly and effortlessly, with direct gaze manipulation of locomotion and objects within the virtual world. This is illustrated by object manipulation, where the experiment showed that objects were very effectively manipulated by gaze. A control action can be applied by eye and then gaze control is deactivated to enable the user to see the effect of the action and to look at the objects nearby. Gaze-based gestures may be a potentially fast way of achieving this, and are quite analogous to the real world – for example, if we wish to walk toward the door we first look at it, look at the path between ourselves and the door, and then move toward it – surely this should be the same in virtual worlds? Then with more accessible (and probably more immersive) interfaces the users' avatar gaze direction would indicate the direction to walk with no further control required – preliminary work on this has already suggested that gaze may be more efficient than the standard method of desktop mouse for locomotion control – as we look and gaze where we wish to go. It is now time for the providers of virtual worlds to add these accessibility functionalities to their worlds.

Using gaze to interact with virtual environments as a modality for disabled users is still at an early stage of investigation but it already holds much promise for a method of liberating these users into a Second Life where they may choose to be disabled or not. The challenges of using gaze alone to interact in real-time (or close to real-time) with virtual environments are considerable, but if these can be met by more accessible (and helpful) interface design then there will be greater opportunities for disabled users to participate fully in virtual communities; but until this control is fully realised then disabled users may feel that they have challenges to their choice of on-line privacy.

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Keeping an eye on the game: eye gaze interaction with Massively Multiplayer Online Games and virtual communities for motor impaired users

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ABSTRACT

Online virtual communities are becoming increasingly popular both within the able-bodied and disabled user communities. These games assume the use of keyboard and mouse as standard input devices, which in some cases is not appropriate for users with a disability. This paper explores gaze-based interaction methods and highlights the problems associated with gaze control of online virtual worlds. The paper then presents a novel 'Snap Clutch' software tool that addresses these problems and enables gaze control. The tool is tested with an experiment showing that effective gaze control is possible although task times are longer. Errors caused by gaze control are identified and potential methods for reducing these are discussed. Finally, the paper demonstrates that gaze driven locomotion can potentially achieve parity with mouse and keyboard driven locomotion, and shows that gaze is a viable modality for game based locomotion both for able-bodied and disabled users alike.

1. INTRODUCTION

In the last few years, the popularity of on-line games and virtual communities has grown enormously. The Massively Multiplayer Online Social Game (MMOSG) of Second Life, for example, has over 14 million members (Linden, 2008) and can support interest groups, cooperative activities between people as well as serious commercial activities. On the other hand, the Massively Multiplayer Online Role Playing Game (MMORPG) of World of Warcraft is more focused on character development achieved through completing game related goals. World of Warcraft has more than 10 million users worldwide (Blizzard, 2008). Profoundly disabled people can find great satisfaction and enjoyment from participation in such virtual communities (Stein, 2007) and can choose to reveal as much, or as little of their disability as they choose visually, by creating their own avatar.

Users with motor impairments often retain good control of their eye muscles when fine motor control of other muscle groups is lost. Eye movement can be used very effectively for interacting with computers, although most of the existing work on gaze based interaction for disabled users focuses on 2D desktop applications and text entry (Lankford, 2000; Majaranta & Raiha, 2002; Hornof & Cavender, 2005). However a number of general problems exist with gaze-based interaction and the migration to the control of 3D graphical worlds. If gaze is the only modality being used, then mouse clicks are often emulated by a slight stare, or dwell, at a location on the screen. The 'Midas Touch' problem arises when unintentional clicks are generated by the user looking naturally at the same place on the screen (Jacob, 1993). The most common solution to this is to use deliberately long dwell times. However, these can be fatiguing and can result in the gaze point moving off the intended target before the end of the dwell period. Another problem arises where the point of input and the point of feedback are spatially disparate, and the user has to look repeatedly between the two (Istance et al, 1996).

User interaction with these virtual worlds needs to accommodate many more tasks than before, such as navigation in 3D space. It also faces the added challenge of requiring fast real-time interaction if participation by disabled users in a world or game is to be on an equal footing as other able-bodied participants (Bates et al, 2008). The usual type of 'dwell-to-click' interaction is too limited for the extended range of tasks where a

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variety of interaction techniques using mouse and keyboard are used in quick succession by able-bodied users.

2. EYE CONTROL IN MMOGS

2.1 Interaction

The typical method of interaction in MMOG environments is via a combination of mouse and keyboard; with avatar movement normally being performed using cursor keys (or the W, A, S, D cluster of keys). However, the mouse is often an option for movement control, both in point-to-navigate games and also those games that offer a movement interface. This is the case in Second Life; by clicking on directional arrows located on semi-transparent movement panels. Camera movement can also be performed by using a mouse with a similar panel. In fact, tasks in all categories can be performed using a mouse, with object manipulation and application control being performed using drop-down menus, transparent pie-menus (figure 1) and dialog boxes.

Figure 1. *Pie menu is Second Life that allows different actions to be performed on an object (Istance et al, 2008a).*

2.2 Problems with Basic Input Device Emulation

One approach to using eye gaze as an input device is by straight forward emulation. Mouse emulation can be implemented with the system cursor following the user's point-of-gaze on the screen. To perform a mouse click then either a secondary input device is used or an eye gaze based selection methods is used, such as dwell time. In addition to mouse emulation there are possibilities to emulate other input devices. There are several ways to perform joystick emulation such as, using an onscreen joystick with gaze friendly command buttons or by the cursor moving incrementally based on the user's point-of-gaze. A keyboard can be emulated by using an onscreen keyboard or by more novel methods such as those used by Dasher in which, text is entered by 'flying' into predicted text. Typical emulation problems include:

- Functionality – Gaze based emulation needs to represent all of the possible functions and have ways of switching between them with a minimal cognitive overhead. E.g. a mouse usually has at least two buttons and often a central wheel that is used for scrolling. In addition, multiple interaction techniques can be used on each such as click, double click and drag.
- Interface design – Most interfaces have not been considered for use with eye gaze and have often been designed to make full use of mouse interaction methods and the functions that they represent.
- Accuracy – Difficulties arise from eye tracker accuracy and these become apparent when pointing at small targets, such as those found in 2D interfaces. Selection of such targets can also be difficult due to 'cursor chasing', occurring when the cursor position and the point-of-gaze are offset due to the inaccuracy and also eye drift occurring during dwell selection.
- Freedom – Normal mouse use allows the user to look at one part of the screen whilst pointing the cursor at another or even removing the hand from the mouse altogether. The same applies to keyboard and joystick input.
- Latency – There is response latency caused by the detection of eye movement, its interpretation, the mapping to a system event such as a key press and finally any latency in the application responding to the event.

No matter what device is being emulated most applications have no knowledge of the input device being used and that the cursor movement and button events originate from an eye tracker.

Some of these problems found can be traced back to the Midas Touch paradigm that arises due to the eyes being an always on device; the eye is a perceptual organ designed for looking at objects rather than controlling them (Jacob, 1993). Due to the inherent inaccuracies of the eye tracking system it is common to move the system cursor over objects that are close to the desired object. The Midas Touch turns this inaccuracy into a selection error if a control action is applied.

Previously, we have investigated the feasibility of gaze based mouse emulation for interaction with online virtual environments (Bates et al, 2008a; Vickers et al, 2008). We found that due to the real-time requirements for interaction in such environments there was a need to switch rapidly between mouse emulation modes. There also needed to be a method of disengaging gaze control so as to observe the environment without fear of Midas Touch selection. Additionly, a similar method was required so as to avoid problems with distraction, e.g. during locomotion style tasks the participant "walks where they are looking", meaning that they are unable to observe the world in the periphery whilst walking.

2.3 Finding Solutions

Most gaze control systems have a facility to pause or suspend active control. However, this is often not used as the cognitive overhead in doing so is prohibitive. One element in a solution therefore is to incorporate a very lightweight process to turn gaze control off. Another is to support several modes of mouse, keyboard or joystick action simultaneously and to have a similarly light weight way of switching between these. One such method is by using glances and detecting when a glance or "flick" of the eye off the edge of the screen occurs. Each directional glance could represent a different mode of operation.

The use of modes in the user interface is not a new concept and was once considered bad practice due to the overhead of remembering which mode was currently in operation (Nievergelt & Weydert, 1987). There are also potential difficulties in the user remembering where each mode is located and how to switch between them. Therefore, for moded operation to be successful, there are a number of design requirements that should be met such as:

- Movement and actions needed to accomplish the task should be efficient.
- Low effort associated with using the mode and with changing between the modes.
- Easy to remember how the modes work and how to activate them.
- Clear feedback about the mode the user is currently in.

2.4 Snap Clutch: a Flexible Gaze Based Input Event Emulator

Snap Clutch (Istance et al, 2008a) is a gaze-based mouse emulator which has 4 modes of operation and uses gaze gestures in the form of off-screen glances to switch between modes, see figure 2. Feedback about the current mode is given by the shape and colour of the cursor.

The modes in our initial implementation of Snap Clutch were based on using *interaction technique* modes. In addition to left click and left drag, we also added a "turn gaze off" and a "park the cursor here mode". Initial trials showed that having the ability to rapidly switch between different mouse emulation modes, had the potential to offer a more real-time interaction experience than normal mouse emulation. Additionally, it offered one approach to resolving problems that can occur due to the Midas Touch.

Although these Snap Clutch modes offered an improvement in task time over normal mouse emulation, when compared to using a hand mouse times were still significantly longer.

3. AN EXPERIMENT

3.1 Task Based Modes

In order to improve on task performance the idea of *task based* modes is introduced, which are to be used together with a selection of the previous *interaction based* modes.

A 'locomotion task' mode provides a means of moving the avatar by introducing active in-screen regions which respond to the gaze position rather than to the system pointer position. This mode causes a stream of keystroke events to be generated which the application recognizes as movement control commands. The user is now free to look around while the avatar moves forward. Glancing to the far left and right regions of the screen causes the avatar to rotate, see figure 2. Stopping the movement is achieved as before by switching the mode off (glancing off screen).

Figure 2. *Screenshots showing Extended Snap Clutch being used with World of Warcraft. The 'no control' mode with overlay zones for rotating the avatar left and right (left); the 'locomotion' mode with overlay zones for moving and rotating the avatar (right).*

The 'no-control' mode has been enhanced by making the avatar rotate when the user looks at the left or right edges of the visible world. This is now a natural response of the world to the users gaze behavior, see Fig. 2.

New mouse emulation modes have been developed to suit particular interaction techniques. Pie-menus are used extensively in Second Life, therefore, a suitable mode was designed and implemented for their use in which the first dwell generates a right button click and the second dwell generates a left button click.

The interface to the emulator enables interactive selection of the modes to be associated with each edge of the screen. This opens the way to having transparent overlays to enable the user to change the mode associated with each edge of the screen at run-time, see figure 3.

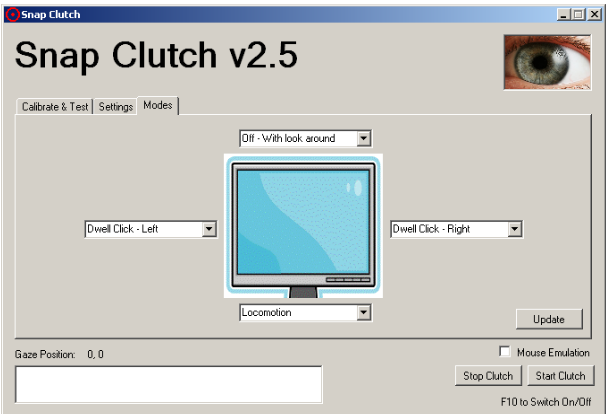

Figure 3. *Screenshot showing the Snap Clutch mode selection screen. The user can choose four modes to suit the application and assign them to an off screen glance of their choosing.*

It was our intention from the outset that these application developments would not be software specific and so far we have been successful. New developments are tested using other MMO style games for compatibility and also for generating new task modes; figure 2 shows Snap Clutch being used with World of Warcraft.

We performed an experiment (Istance et al, 2008b) where the participant used Second Life using two input conditions: keyboard and mouse and gaze interaction using Snap Clutch. We then analysed the error conditions in order to be able to focus further development efforts more efficiently. The four modes used can be chosen according to the actual application. In this experiment we used the following:

- Glance up – Unconstrained looking around
  - No action on dwell.
  - Rotate left when looking inside the left hand edge of the screen.
  - Rotate right when looking inside the right hand edge of the screen.

- Glance left – Left button click
  - A gaze dwell causes a left button click.
- Glance right – Right button click
  - A gaze dwell causes a right button click.
- Glance down – Locomotion
  - No action on dwell.
  - Streaming of ‘W’ keystroke events when the user looks in the main part of the screen.
  - Streaming of ‘A’ and ‘D’ keystroke events when the user looks into small regions in the left and right hand sides of the screen causing the avatar to rotate left and right whilst walking forward.
  - Streaming of ‘S’ keystroke events when the user looks inside a thin strip at the bottom of the screen causing the avatar to walk backwards.

3.2 An Approach to User Performance Investigations

The initial pilot study demonstrated that using Second Life with our gaze-based interaction technique resulted in distinctively longer task completion times than when using conventional interaction techniques. In order to achieve parity of gaze interaction with normal keyboard and mouse, it is necessary to be able to identify the usability issues with gaze control. This will allow us to understand what influences the speed of interaction (time of task completion) and the type of errors that are made.

The partitioning of task time into productive time and error time has long been a feature of usability engineering (Glib, 1984). The time spent in a specific error condition represents the potential time to be saved in task completion if the cause of that error can be removed. This relative saving in task completion times by addressing each type of error represents a kind of cost saving benefit of redesigning different features of the user interface.

3.3 Participants and Apparatus

The study involved twelve participants. Ten of them were students and two were university lecturers, who were experienced users of gaze interaction. Ages varies from 20 to 56 with the average being 29. All participants were able bodied. The study was carries out using a Tobii T60 screen integrated eye tracker and all the task executions were recorded using TeamWork screen capture software.

3.4 Tasks

Two sets of three tasks were devised and carried out within a purpose built Second Life environment that represented the university computer science building. These were based on Hand’s (Hand, 1997) proposed taxonomy of main control and manipulation areas present within virtual environments. They were as follows:

i) Locomotion – The participant was required to walk from the main entrance, up the staircase and go into a room where there were display panels about individual university modules, see figure 4. The task required the participant to retrieve a module code from a particular panel. Each participant set were required to retrieve a different module code from a different panel.

ii) Object manipulation – The participant was required to change a slide or a web page from within the main lecture theatre and accept the change using a dialog box. One subject set changed the presentation slide by ‘touching’ a button on a control panel located on the stage. The other participant set caused a web page to be displayed by ‘touching’ another button that was located near the stage. To achieve this task both sets of subjects were required to perform a right click to display a pie menu and then a left click to select the ‘Touch’ menu item.

iii) Application control – The participant was required to change the appearance of their avatar. One participant set was to remove the moustache and the other was to raise the height of the eyebrows. To achieve this, the participant was required to use a pie menu as described previously but with the selection of the ‘Appearance’ menu item. This caused a dialog box to appear and the subject then had to select a group of features to edit from a panel of vertical buttons. A horizontal slider was used to change the selected feature.

3.5 Procedure

The twelve participants were split into two groups of six. One half did one task set with the keyboard and mouse, followed by the other task set using gaze control. The other half started with gaze control followed by keyboard and mouse. All subjects with the exception of the two experienced participants had not used Second Life before, nor did they have any previous experience of using gaze control. Each participant was given a fifteen minute introduction to Second Life followed by a fifteen minute introduction to using gaze control. This involved a series of simple training exercises.

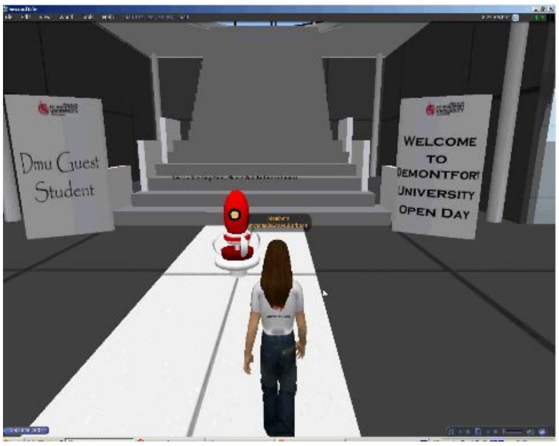

Figure 4. *Screenshot of a subject performing the locomotion task.*

Each task set began with the avatar in the same place, standing at the entrance to the building. Tasks were completed in the same order for all subjects: locomotion; object manipulation; application control. The task was first explained and then the participant was asked to complete it. If required, the participant was reminded of the task during completion. All participants were asked to complete a brief questionnaire upon completion of the two task sets. They were advised that they could withdraw from the trial at any time. Each session took between 45-55 minutes to complete.

3.6 Analysis and Results

We identified four different categories of errors that the subjects made during the tasks. These were to be annotated upon the videos using an open source video annotation application called Elan. The video data from one subject was marked up by two people so that consistency of the outcomes could be checked. As a result there were minor adjustments made to the error categories and definitions but for the most part there was a high degree of agreement between the two analyses. The four main error categories were as follows:

i) Locomotion error – being one of the following,
- Unintentional motion backwards (the gaze point first moves through the 'move backwards' zone of the screen after glancing down to change into the locomotion mode).
- Unintentional rotation left or right (the subject means to glance off screen to change modes when in 'no control' mode, but rotates the avatar instead).
- Turn overshoot (the subject deliberately turns while in 'locomotion' mode but turns too far and has to correct).
- Walk overshoot (the subject tries to stop, but the change to 'no control' mode takes too long and the avatar walks to far and subsequently has to reverse).

ii) Mode change error – an unintentional change of the mode; a subject tries to rotate left or right, in 'no control' or 'locomotion' mode but changes mode by mistake by looking too far off screen.

iii) Accuracy error – a subject tries to select a target but misses due to inaccurate pointing.

iv) Misunderstanding error – a subject misunderstands / mishears / forgets what to do.

For each subject and for each task the total time spent in each error condition was subtracted from the total time, leaving us the non-error time for each trial. The outcome of the trials for the three tasks is as shown in figure 5 and table 1. Table 1 shows the tasks along with the average error-free time; the total error count; the total error time; the percentage of error time. This is also represented in figure 5 but with the error-time divided into their associated error categories.

One of the subjects had difficulty in calibrating the eye tracker. She was able to complete all of the tasks in the gaze condition but the number of accuracy errors was far greater than the other subjects with more than 3 standard deviations from the mean. Consequently all data from this subject was removed from the analysis.

Table 1. *Average task times, error counts, error time and error percentage for all tasks (kbm = keyboard and mouse)*

Task	Condition	Error free Time (s)	Error Count	Error Time (s)	Err %
Locomotion	*Gaze*	57.97	4.55	21.4	22.68
	KBM	47.13	0.18	1.32	2.54
Application	*Gaze*	79.25	3.09	41.75	29.91
	KBM	40.15	0.45	2.73	5.95
Object	*Gaze*	18.99	2.45	21.89	50.05
	KBM	7.84	0.18	1.05	6.1

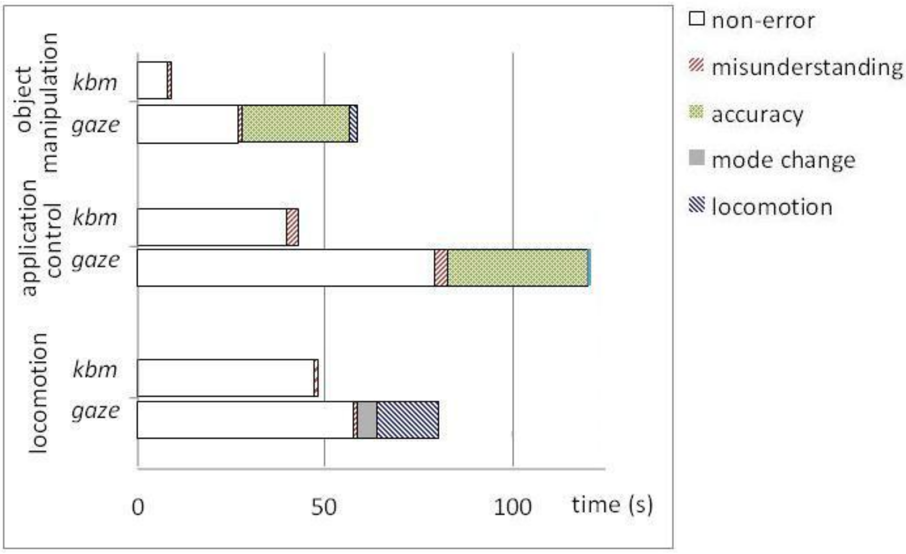

Figure 5. *Average task completion times partitioned into error times (in four types of errors) and non-error times*

The results show that all subjects were able to complete the three tasks using eye gaze. The non-error time enables comparison of task times if the cause of the errors can be removed through design changes. The non-error times for gaze is encouraging, especially those for the locomotion task. With only a short training session, subjects would be able to complete the locomotion task using gaze almost as quickly as they would using a keyboard, if the cause of the locomotion errors could be removed. The reasons for the locomotion errors were partly due to the speed of movement by the avatar in response to the key commands generated by Snap Clutch. This caused overshooting and undershooting of avatar movement that would need to be corrected. The processing pipeline in using a single computer is a significant contribution to this: eye tracker – emulator (Snap Clutch) – Second Life (additionally, in the experimental condition, the video capture software). There are also possible optimisations that can be made to improve the emulator software. Another source of locomotion error is the location of the backwards motion overlay zone at the bottom of the screen, see figure 3. The gaze position has to travel through this zone after changing into the locomotion mode and combined with the latency within the system an unwanted backwards movement results. These issues can be addressed within the implementation of the locomotion mode in addition to examining causes for response latency.

The biggest cause of errors in the application control and object manipulation tasks is the difficulty in hitting the small control objects within the dialog boxes. This was exacerbated by latency in generating click events probably due to the processing pipeline. One solution to reduce these types of errors is to incorporate some form of zoom interface that is common within 2D gaze driven interfaces.

4. CONCLUSIONS

In this paper, we have discussed some of the problems associated with gaze based mouse emulation and their effectiveness for use in online virtual environments such as Second Life. Our initial studies highlighted key problem errors which, we were able to partly address in the implementation of emulator software. To improve further we moved from using *interaction technique* modes to *task based* modes.

The study has been successful in identifying the extent and causes of the difference in performance between the gaze and keyboard-mouse conditions. This has revealed specific design changes that address these differences and also gives an indication of the likely performance improvements. Importantly however, it has demonstrated the feasibility and potential for gaze based interaction with online virtual environments. In particular that of gaze based locomotion, in which there lies real possibility that eye gaze can achieve parity with that of mouse and keyboard when performing such tasks.

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Visual eye disease simulator

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ABSTRACT

Visually impaired people have a very different view of the world such that seemingly simple environments as viewed by a 'normally' sighted people can be difficult for people with visual impairments to access and move around. This is a problem that can be hard to fully comprehend by people with 'normal vision' even when guidelines for inclusive design are available. This paper investigates ways in which image processing techniques can be used to simulate the characteristics of a number of common visual impairments in order to provide, planners, designers and architects, with a visual representation of how people with visual impairments view their environment, thereby promoting greater understanding of the issues, the creation of more accessible buildings and public spaces and increased accessibility for visually impaired people in everyday situations.

1. INTRODUCTION

It is very difficult to understand and appreciate visual deficiencies from simply a description or static image. It is much easier to see how vision is affected through an actual visual simulation of the situation (Addison and Thiebaux, 1998). One area in which this is of particular significance is in the design of homes, buildings and public spaces. This is an important area of consideration for reasons of social inclusion, legislation and increased personal safety. By providing architects and designers with a tool that enables them to 'see' their designs through the eyes of a visually impaired user, they should be able to produce more accessible designs that will allow people with visual problems to access buildings/public spaces more easily thereby improving their quality of life.

To date most of the work in this area has focused on simulating eye diseases/conditions to give an insight into how a person's vision might be affected by them (Ai et al, 2000). For example, Webb et al (2003) used an immersive environment to display in 3-D the anatomy of the eye to illustrate, for training purposes, the progression and effects of different eye diseases as well as demonstrations of corrective procedures that could be undertaken. Jin et al (2005) created a virtual apartment, and applied masks to this image to simulate various eye diseases. This application was designed as an aid to student doctors, to allow them to experience visual impairments, so that they may be able to recognise these symptoms in patients. The researchers also hoped that it would help in convincing non-compliant patients how serious their particular disease was.

Other earlier work in this area has been based around individual eye conditions, and has used less technological methods. One project (Zuckerman et al, 1973) investigating cataracts used petroleum jelly spotted onto a glass lens to simulate the effect of the cataract on the incident light reaching the eye. Work has also been carried out by Eliott et al. (1996) and Crabb et al. (1998). The website for the Royal National Institute of Blind People (RNIB, 2007), offers a large number of products and services for good design of websites, literature and products, as well as the ability to use them as a consultancy service for help with accessible building designs. The inclusive design toolkit (Clarkson et al, 2007) supplies a range of resources, information and help to designers. The tools they supply include both physical (e.g. sets of glasses with damage applied to them for eye disease simulation) and software (e.g. adjusting the contrast of a photo). The University of Reading also undertook Project Rainbow (Bright and Cook, 1996), which produced two advisory papers, looking at good and bad design practice, along with other aspects of the internal building environment. The Vision 2005 conference (Various 2005) covered a large number of different issues relating to people with visual impairments. Amongst these were several papers looking at good design for the internal environment. These were all in the form of good practice guidelines, as with Project Rainbow.

However, despite the initiatives described above, architects still generally only have guidelines to work with, rather than the ability to visually represent their designs as they will be perceived by people with visual impairments. The ability to combine the use of traditional CAD (Computer Aided Design) files etc. with software designed to simulate eye diseases, should make accessible design easier and the resultant buildings and public spaces more effective (Kellas, 2004; Manning, 2006).

2. EYE DISEASES

The eye is a very complex and delicate structure, which can be damaged in many different ways. Some damage can occur with little to no effect on vision, whilst other forms of damage have a significant detrimental effect. The effects of many different eye diseases were researched in order to find those most suitable for simulation as well as those which most commonly affect people's vision (NEI, 2007). From the collated information the following were chosen to be simulated in the early prototypes.

2.1 Macular Degeneration

Macular degeneration is a disease of the eye most commonly found in elderly adults where the centre of the eye (the macular) becomes damaged resulting in the loss of central vision and an inability to see finer details. There are two types of macular degeneration, wet and dry (RNIB, 2007; St Luke's, 2007). Visual symptoms of macular degeneration include:

- Loss of central vision
- Distorted vision (e.g. straight lines appear wavy)
- Blurring of the vision.

2.2 Glaucoma

Glaucoma is a group of eye diseases caused by damage to the optic nerve. The diseases fall into two main categories (Glaucoma Org, 2007); open and closed angle glaucoma. In both cases the pressure in the eye rises and causes damage. Visual symptoms of Glaucoma include:

- Vision becomes misty
- Loss of peripheral vision.

2.3 Cataracts

Cataracts are most common in older people and are a condition of the eye whereby the lens becomes clouded. This clouding can affect only a small part of the lens or the entire lens (NHS, 2007). Cataracts tend to form slowly and many people do not notice they have them. Visual symptoms of cataracts include:

- Blurring of the vision
- Double vision in one eye
- Spots in vision
- Halos around bright lights

2.4 Diabetic Retinopathy

Diabetic Retinopathy is the most common cause of blindness in the UK. It is caused by damage to the blood vessels in the back of the retina (NHS, 2007). Visual symptoms of Diabetic Retinopathy include:

- Tiny dots appearing in vision
- Dark streaks across vision that can sometimes obstruct it
- Blurred vision
- Poor night vision

2.5 Colour Blindness

Colour blindness is a deficiency in colour vision normally attributed to genetic factors; however it can also be brought about by damage to the eye or brain (Wikipedia, 2007). Those affected find it hard to distinguish between two or more colours (Vischeck, 2007).

3. SIMULATING DISEASES

After studying the characteristics of the common diseases outlined above, a number of types of eye effects were identified as needing to be simulated in order to model diseases effectively. These included:

- Colour Effect – changes the colour of the image
- Twist Effect – applies a pinch/twist effect to the image.
- Dots Effect – adds a number of random dots to the image
- Fade Effect – fades the image out
- Texture Effect – applies a texture to the image
- Blur Effect – applies a blur to the image
- Double Vision – applies a double vision effect to the image
- Darken Effect – darkens the image

These effects were implemented using image processing techniques to manipulate the images and produce the simulations. The system uses Microsoft DirectX and C#. The image processing was carried out on the graphics card using HLSL (High Level Shader Language) which dramatically speeds up the image processing, an important consideration if complex scenes are to be modelled and/or if real time processing is to be undertaken (e.g. during actual walkthroughs of buildings). Individual effects were implemented as follows:

3.1 Blur

The obvious type of blur to use is a Gaussian blur which provides a good realistic image that is easily adjusted. However due to limitations of HLSL, the number of samples required to model the impairment (49 samples for a typical example) exceeded the maximum that HLSL can handle and therefore in order to deal with the shortcomings of HLSL, a two pass blur technique was used instead.

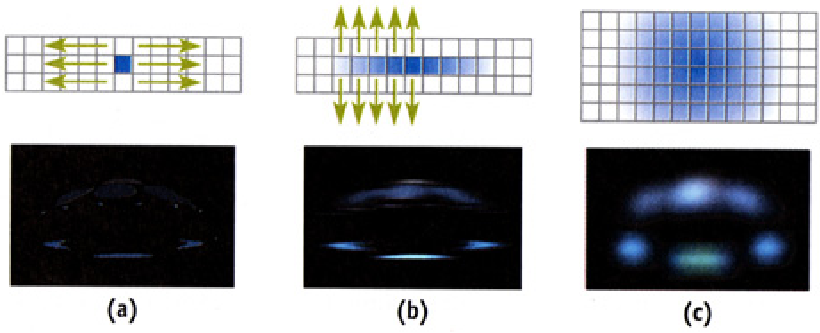

Figure 1. *How the 2 pass blur works. (a) Initial image. (b) Result of horizontal blur. (c) Final result. [16]*

Initially a horizontal pass causes blur to occur along the horizontal axis see Fig. 1 (b). Once this has occurred, a second pass is carried out this time on the vertical axis see Fig. 1 (c). This completes the effect and produces results that are close to that of a Gaussian blur as well as being very much quicker when calculated in real time (James and O'Rouke, 2004).

3.2 Texture

Some eye effects required a texture to be drawn over part of the image as shown in Figure 2. This allows for damage to be shown and areas of the image to be blocked. This was carried out by overlaying an image on top of the original image and has the advantage that different textures can be applied for different conditions, severity of condition or specific symptoms of the disease occurring for a particular individual.

3.3 Brightness and tint

The brightness of the image can also be altered or a colour tint applied to allow a number of eye conditions to be simulated, such as macular degeneration where the image appears to be washed out (brightness increased). Brightness is implemented in a similar way to applying a colour tint. An increase in brightness can be brought about by a white tint (red, green and blue increased by the same amount) and a decrease in brightness by a black tint (decrease in red, green and blue by the same amount). In order to calculate the new colour of a pixel, the tint percentage for red, green and blue are used. The pixel's red value is multiplied by the tint percentage of red. The same is done with green and blue. The result is an image with a tint defined by the percentages given. If the percentages range from 0 to 200, the amount of each colour in the image can be increased and decreased. Colour draining, whereby colours are filtered out to black and white can be used to simulate colour blindness and general colour loss. It can also be used to place a smoked haze over an image by increasing the yellow content of the image, an effect described by some glaucoma sufferers who likened the effect to the tobacco filters used in photography.

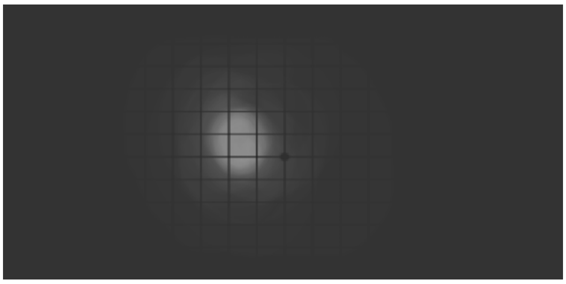

Figure 2. *Example of texture being drawn on top of a grid. Part of the Glaucoma effect.*

3.4 Line Distortion or Pitch

Some of the eye effects involved the area of damage to have a twisted pinch like distortion see Figure 4. This effect requires adjustment through vector mathematics. An initial point can be specified for the centre of the damage as shown in Figure 3.

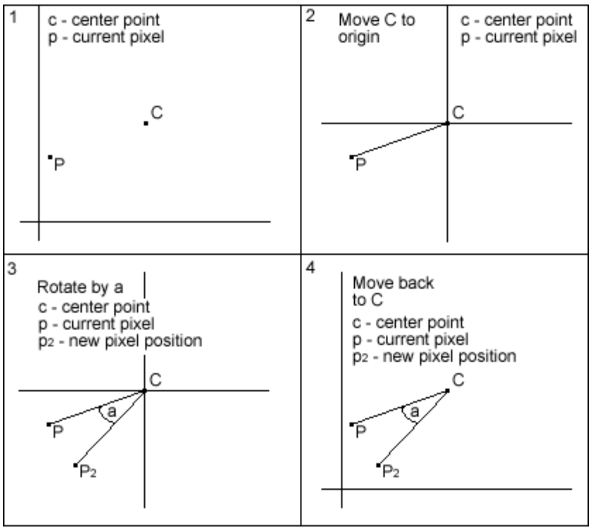

Figure 3. *Rotation calculation - vector is found between P and C in 1 ands moved to the origin in 2; rotated by the angle (related to distance from C) in 3 and finally moved back to C in 4.*

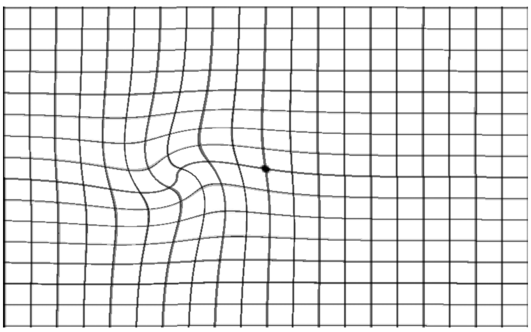

Figure 4. *Example of the Pinch/Twist effect on a grid.*

With this centre point, each pixel can be tested to see if it is within the specified radius of damage. If it is, the vector from the pixel to the centre of damage, is moved to the origin, rotated and then returned to the centre of damage. This causes a rotation of a ring of pixels. If this rotation is varied with distance from centre of damage, it is possible to simulate a pinch distortion effect. This was found to be most effective when using an exponential function.

3.5 Double Vision

Double vision is simulated by drawing the same image twice as shown in Figure 5. The second drawing is offset by a small amount and is made partially transparent through the use of the alpha channel.

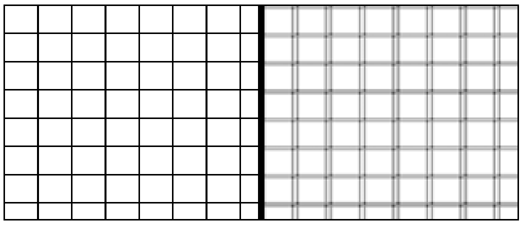

Figure 5. *Example of double vision. Left side is a normal grid. Right side is the same grid with the double vision effect applied.*

4. IMPLEMENTATION

The aforementioned effects allow for individual aspects of eye diseases to be simulated, but in order to complete the full simulation for a particular disease, they need to be combined together. This is achieved by employing an image post-processing framework. In this case, there are scenes for input type (e.g. Image or 3D model), eye diseases (collections of eye effects) and eye effects.

The post processing framework allows the effects to be applied to the scene no matter how complicated it is. The scene is initially drawn to a texture which the post processing framework imports and subsequently manipulates. This allows the effects to appear in real time even in 3D moving scenes.

4.1 Scenes

The two types of scene that have been implemented are an image scene and a 3D scene as shown in Figure 6. The image scene loads in an image of varying formats and this is used as the basis of the simulation. The 3D scene allows a 3D model to be loaded into the program. The mouse and keyboard are used to navigate the scene. For the effects to be implemented, the 3D scene once drawn, is rendered to a texture allowing it to then be treated the same as the image scene. The Video scene is currently under development.

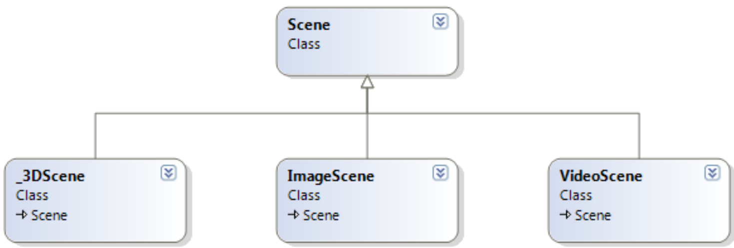

Figure 6. *Hierarchical class diagram of the scene classes.*

4.2 Eye Diseases

The main purpose of the structure shown in Figure 7 is to hold the collection of eye effects. It provides a way of building up diseases by adding and ordering the individual effects. Each of the effects loaded into the program is processed and the resultant image is drawn to the screen.

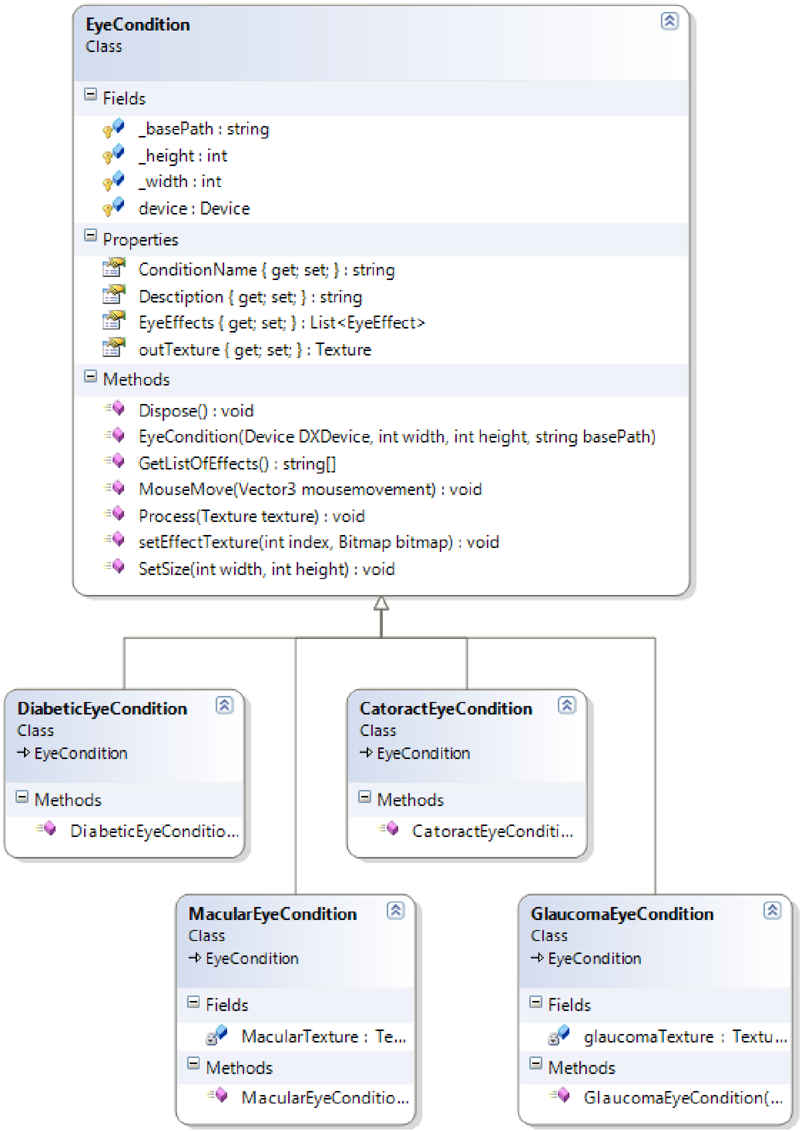

Figure 7. *Hierarchical class diagram of eye conditions.*

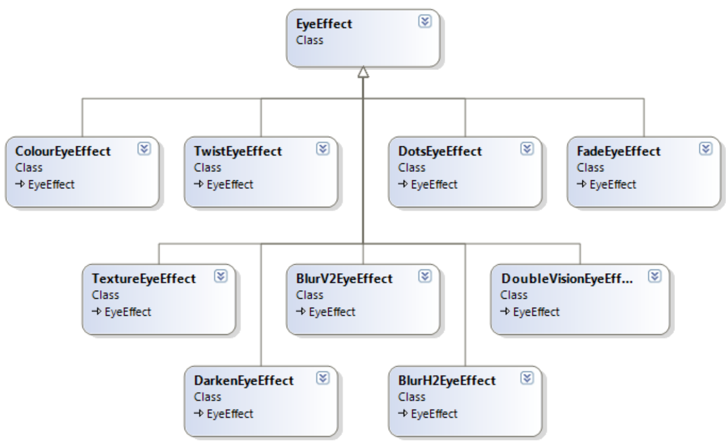

Figure 8. *Hierarchical class diagram showing the eye effects.*

4.3 Eye Effects

The eye effects (Figure 8) are the key to the whole simulation. Each contains a varying way of manipulating the image. As explained earlier most employ pixel shaders which allows direct access to the graphics card, dramatically speeding up the manipulation of the image, allowing for real time simulation.

4.4 System Implementation

The system combines the above component parts with the user interface and the input and output functions. The ability to load in eye conditions and edit them "live", allows for easier building of simulations. Effects can be added and removed to/from conditions and the parameters changed. Once a new condition or a customised one is complete it can then be saved out to an XML file. The system also allows for the image on the screen to be saved as a bitmap image. This can be useful for sharing information with others. With regards to the user interface the menu bar along the top of the program is used for loading and saving data, whilst the editor bar on the right is used for selecting and controlling the eye conditions and effects (Figures 9 and 10).

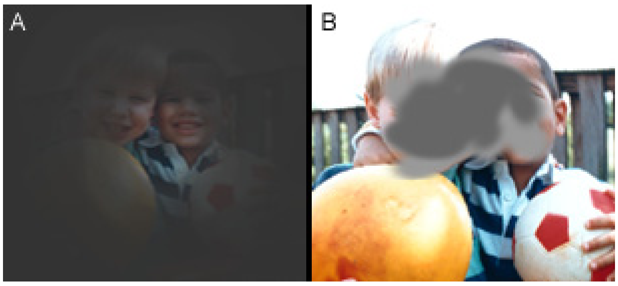

Figure 9. *Output of the simulations from the program. (A) Glaucoma (B) Macular Degeneration.*

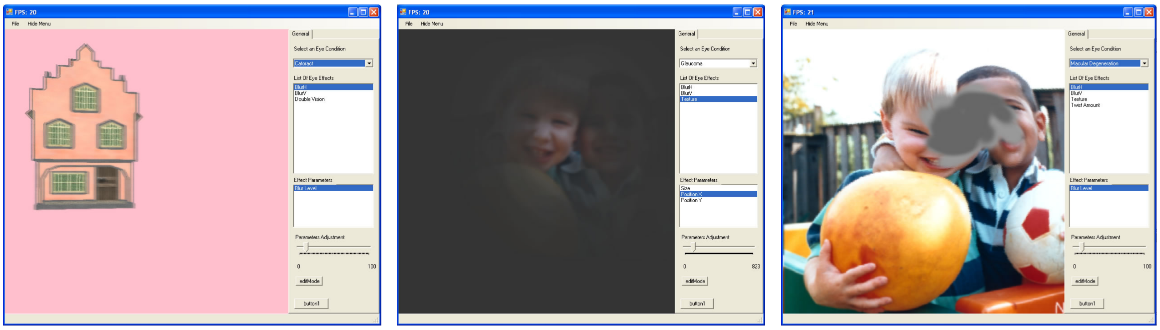

Figure 10. *Output within the context of the user interface*

5. CONCLUSIONS AND FURTHER WORK

Accessibility plays an important role in the design of public buildings and spaces as well as for individual homes. This paper has investigated ways in which eye diseases can be simulated in order to improve the potential for rooms and buildings to be designed with visual impairments in mind. Using the simulator to enable building designs to be viewed through the eyes of a visually impaired user will greatly enhance the potential for better access to and navigation within public buildings and spaces as well as for homes designed with an individual's requirements in mind. The system could also be used to train designers and architects in aspects of inclusive design and accessibility particularly when linked to the good design principles that are already available.

Work is currently underway to increase the complexities of the models that can be imported into the system and to process real-time video data as a designer walks around an actual building. Moving the system into a CAVE-like environment is also under consideration as is the use of object detection algorithms to automatically highlight to designers potential hazards associated with their designs as they progress. We are also in consultation with our construction management colleagues with regard to further features that should be implemented to ensure practical use and value of the system.

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ICDVRAT 2008

Session V

ArtAbilitation
helping through art

Co-chairs: Ceri Williams & Eva Petersson

Aphasic theatre or theatre boosting self-esteem

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ABSTRACT

Aphasia is an acquired communication disorder caused by a brain damage that can affect the ability to speak and understand, as well as to read and write. Aphasia is most commonly caused by a stroke, but it can also result from a traumatic brain injury or a tumor. Having lost normal communication skills, an aphasic victim will often hide and isolate him or herself. This can also occur as a result of a reduced level of activity following rehabilitation. To help cope with this condition and in order to help victims regain their self-esteem, the Aphasic Theatre was created in 1992. The objective was to involve interested victims in drama and theatre as a way to rehabilitating their communication skills and self-esteem. The Aphasic Theatre is today a recognized theater company which has put on plays in Quebec as well as elsewhere in Canada and Europe. There is now an accumulation of recorded evidence, from specialists, aphasic participants and their relatives, audience attending Aphasic Theatre performances as well as a study completed by ESPACE group of University of Montreal, to confirm the validity of this innovative social rehabilitation method (Le Dorze and Brassard, 1995).

1. INTRODUCTION

Even a mild presence of aphasia can interfere with established relationships and as a result can cause serious social isolation. Worst case situations can lead to a complete breakdown with one's surroundings. Indeed, a verbal handicap is itself a significant obstacle for an aphasic person. How can one make real social interactions when one cannot clearly express ideas, opinions, or express perception of things and events? Most aphasic victims become listeners when in a group situation because they can neither contribute to the conversation nor can they entirely understand verbal exchanges. As well as they would like to respond, words are missing and conversation changes too rapidly. Afraid of making mistakes, aphasic persons tend to avoid communication opportunities resulting voluntarily or not isolate and reduced self-esteem.

2. APHASIC THEATRE

In order to overcome the social isolation caused by aphasia, Anne-Marie Théroux, an actress and speech-language pathologist working at the Villa Medica Rehabilitation Hospital in Montreal, developed an original approach to assist the social reinsertion of aphasic people through the practice of drama and theatre. Inspired by Augusto Boal's principals and his Theatre of the Oppressed (Boal, 1978), she started using non-oral drama expression with aphasic victims to reinforce traditional methods of rehabilitation. Then she founded the Aphasic Theatre Compagny so that interested aphasic persons could become involved in communications activities in a successful and pleasant way. The main objective was to create a shared, open, welcoming and respectful environment of peers and professionals.

The Aphasic Theatre offers two types of activities:

- *drama workshops* without any representational aims
- *theatrical play production*

2.1 Drama Workshops

2.1.1 Objectives

- Stimulate:
  - Body, expression and speech skills
  - Pragmatic skills (look, listening, speech rules)
  - Cognitive skills (memory, creativity, reasoning, divergent thought)
- Encourage social interaction and break down isolation
- Develop self-confidence and encourage self-esteem
- Find alternative tools leading to improved communication
- Reinforce autonomy and self-support
- Consider as a main goal the pleasure of communicating

2.1.2 Functioning. Since 1996, the Aphasic Theatre core team consists of a speech therapist and a theatre trained specialist. This qualified partnership can quickly bring the workshops to a high level of efficiency. The participants are surrounded by professionals recognized in their field. The vocal training and exercises that requires a more clinical approach are tasks managed by the speech therapist. This person also handles aphasics victims having to deal with major dysfunctional problems. The theatre specialist focused on the play acting, training and support. Regular meetings evaluate progress and prepare the next workshop.

Aphasic participants not only include persons with language disorders but they may also have hemiplegic and apraxic conditions. Other disorders may therefore also included memory, space orientation, hyper sensibility and other problems. All these conditions are taken into consideration when preparing a workshop.

Two different types of workshops are held at Villa Medica Rehabilitation Hospital, namely:

- **Act one** is a workshop designed for beginners. It includes physical, vocal and memory exercises, as well as sessions based on gestures, facial expression, improvisation.
- **Roll cameras! Action**! Is a workshop to produce a video production. It requires reading skills, memorization, and improvisation in front of a video camera.

Each workshop is held once a week, lasts two hours each and are scheduled in the fall to spring period.

2.1.3 Accessibility. The aphasic person having completed therapy or still in a rehabilitation program can participate in the workshop sessions. Also welcome are victims with other language disabilities such as dysarthria. There are no prerequisites, no discrimination on the basis of speech abilities or other limitations, only the interest to participate.

Figure 1. *Dramatic art workshop.*

2.1.4 Typical workshop planning.

1. Arrival
2. Discussion
3. Physical warm up
4. Vocal warm up
5. Series of exercises:
    - Basic skills
    - Level of confidence (trust)
    - Mime and expressive gesture
    - Memorization-concentration
    - Listening abilities-interaction
    - Expression of emotions
    - Exercise using the imagination
    - Improvisation- character play
6. Feed back

2.2 Theatrical Play Company

Any aphasic person willing to spend more time as an active member of the Aphasic Theatre Compagny can become involved in this activity. It requires that the participant previously attended workshops given by the speech-language pathologist and the theatre specialist. There are no auditions but the future participant must be interested in being part of a new play project. In addition, the Director of a new play may recruit aphasic people attending workshops. The only restrictions have to do with physical endurance and capability of understanding simple instructions. In this environment there is no speech language pathologist and as such the participant must be self-sufficient.

2.2.1 Objectives

- Develop creativity, production and interpretation skills
- Increase self-confidence
- Acquire theatrical skills
- Develop speech abilities in front of an audience
- Encourage interaction and listening abilities
- Build a collective project

2.2.2 Play development. The quality of any play performed by the Aphasic Theatre Company is essentially related to the casting of the actors and their respective performances, courage and determination. It also relies on the great capacity of the Play Director to promote talent and to overcome limitations. There is, however, no specific formula to making a success with a theatrical play performed by aphasic persons.

The Aphasic Theatre produces its own play, in order to open acting opportunities and develop aphasic actors consistent with each person's desire to meet goals in a positive and fulfilling way. The play is intended to serve the aphasic people while modestly encouraging his or her perseverance.

Over the years, each Play Director has developed his or her methods and skills to be successful with aphasic actors in various situations, such as:

- Short scenes: work on sketches.
- Mime and spoken scenes: establish an equilibrium involving spoken roles and mime roles.
- Memorization: overcome problems as required and limit lines to be learned even though some actors could handle more lines.
- Rotation and substitution: use two castings for the same role to overcome possible scheduling conflicts (vacations, health problems). This also allows more participants to tour with the play.

- Trust and confidence: by scheduling many rehearsals aphasic actors become more at ease with lines and play acting (entrances and exits). Surrounding the actors with stage professionals also contributes to trust and confidence.

As already noted, the play productions are especially dedicated to informing the population about aphasia as well as present victims through the role they play on stage. It does not involve attracting attention to the specific case of the actor victim.

Figure 2. *Terre Aphasie, directed by Isabelle Côté.*

2.2.3 Production steps. First step: the process begins with identifying what the aphasic person wants to improve through an acting experience. Examples include the ability to learn more lines, develop acting abilities, play a character very different from oneself, acknowledge a talent such as singing and or dancing. For beginners, the simple experience of being introduced to the production process can be a meaningful accomplishment. This step also includes the evaluation of existing and potential abilities and skills so as not to overburden any actor.

Second step: establish the main theme around which the play action will integrate the various communication problems. Although communication is the main reason why the Aphasic Theatre exists, it is not necessary that a play only stress aphasia and one's changed life experience. It does matter, but there is more than this to explore and show as for example to deal with problems of day to day situations.

Third step: develop a scenario and script to commence the first improvisation session. The Play Director will use the improvisation sessions to push forward the creative process in an interactive way, varying actors and emotions, fashioning the play until images, sketches and scenes are established. The Director's challenge is to find a way to adapt his vision for the play with the capabilities of the aphasic actors.

Forth step: putting all the previous work together to achieve the final play version. The Play Director may come up with a text inspired by the improvisation sessions or the actors may be asked to write their own texts or the Director may rewrite a previously prepared text. Rehearsals can commence and this will be followed by further adjustments. When the play is finally performed, the full capabilities and talents of the aphasic actors are put on stage for the audience to appreciate.

3. ADVANTAGES

3.1 Field Level Feedback

After more than ten years of Aphasic Theatre activity, field evidence supports the conclusion this approach is relevant and efficient in improved aphasic person communication deficiencies, social activity and self-esteem. Feedback obtained from aphasic participants, family members, play audiences, involved theatre professionals, speech language pathologists and other people points to the value and significance of workshops and play acting as key to aphasic victim well-being. Aphasic people are quick to point out that workshops and play acting are much more than recreational activities. They result in more and better interaction with relatives and strangers and with less stress. In comparison with aphasic people who do not participate in this way, they are happier and less depressed. They also have more tools to rely on to be understood. Self-confidence is heightened and shyness diminishes.

Being part of a theatre play is rewarding in regaining self-esteem especially if one performs in front of a live audience. The approval and congratulations that come with applause, smiles and tears can be exhilarating as well as reward for the courage, time and hard work put in. The feedback provided by aphasic actors is clear and positive. In addition, they gain a strong sense of purpose by helping to educate the public. The audience itself is better informed and is made more aware of what the aphasic person faces in his or her everyday life.

3.2 Testimonials

Here are some testimonials grasped among aphasic people, relatives and speech-language pathologists in touch with the Aphasic Theatre's approach:

Lise, an aphasic member of the theatre company:

> *I am living with aphasia and I thought that my life was over. But I was completely wrong. It is only different.*
>
> *I had the opportunity to join the Aphasic Theatre. There is a great deal of laughter with a bunch of joyful people: you find comfort, you welcome new members, help others, encourage them, you create and tour. You meet other aphasic people dealing with other physical or speech disorders. Some of them are more severe than others. But one thing still remains, the ability to speak easily and spontaneously is missing. Words are there but not right away when you need them. The common goal for all of us remains in the firm desire to express our needs and ideas.*

Francine, an aphasic participant's daughter:

> *On the 20th day of January, I saw the play «Je vous lègue ma folie». Martial, my father took part in it as an actor... I had never thought that one day my father would be on stage and perform in a theatre production... Afterwards, I was astonished by all the work done by each actor, as well as their teacher. I believe that the Aphasic Theatre is an answer to my father's needs. Now I understand why it was so essential for him to be part of it.*
>
> *That very night, I understood what the message of that play is: live intensively each and every moment, and how each individual on stage had to deal with their abilities. I know, of my father's disability and after seeing the production, I was more aware of all the different types of aphasia and how challenging life is for an aphasic person... I believe that the Aphasic Theatre helped my father to break through barriers, use all his will to keep trying to talk more and have fun on stage.*

Gisèle, speech-language pathologist:

> *Sometimes severe forms of aphasia can limit our individual clinical approach for rehabilitation. I have to recognize that we cannot always meet the needs. We do know that some aphasic people will stay with limited speech abilities but their needs to communicate and interact with their relatives still remain. The Aphasic Theatre provides a means to express them and that is priceless…*

3.3 ESPACE Group Study: What effects does the participation in a theatre workshop have on individuals affected by aphasia

A study was commissioned to confirm field level feedback as well as to evaluate in an objective manner the rehabilitation results when aphasic people involve themselves in Aphasic Theatre workshops and plays. The study was carried out by ESPACE Group, from the School of Speech-Language and Audiology, University of Montreal. That research focused on the psychosocial consequences attributed to communication problems including those associated with aphasia and specifically the effect resulting from attendance and participation in Aphasic Theatre workshops and play. Financial support was provided by a scientific research fund, FQRSC, Fond Québécois de la Recherche sur la Société et la Culture. Specifically, the study examined 3 key issues:

i) Aphasic people everyday habits;
ii) Communication abilities;
iii) Relationships and interactions with relatives and social environment.

The study methodology comprised both a quantitative and qualitative component and a before and after theatrical plays comparative component.

Four groups of aphasic people were recruited:

- aphasic actors having participated in theatrical plays;
- relatives or close persons in support contact with aphasic persons;
- aphasic persons control group;
- relatives or close persons in support contact with aphasic persons control group.

Quantitative tools were used to evaluate life habits (MHAVIE: Mesure des Habitudes de Vie, Fougerollas and Noreau (1998), communication skills (FACS: Functional Assessment of communication Skills for Adults, Lomas et al, 1989) and perception of relatives (Adjective Check List, Gough and Heilbrun, 1983). A semi-structured interview method was used for the qualitative assessment of aphasic persons and their relatives. The data was compiled separately for each of the four groups. The data was then analyzed for adaptation process.

Preliminary study show an improvement in an aphasic people's performance of everyday activities and communications in a group setting when he or she been involved in theatrical plays. At the same time, the data shows relatives or partners perceive the aphasic member in a more positive way and that they are more satisfied with his or her every day performance. The qualitative data assessment shows definite improvement of self-esteem for aphasic persons who have undertaken the theatrical play experience. The study therefore supports the conclusion that the Aphasic Theatre approach and methods are productive and effective and as such represent a valuable contribution to rehabilitation and improved self-esteem. It also suggests it is a cost/benefit and efficient means to rehabilitation and the promoting of self-esteem for aphasic persons.

4. CONCLUSIONS

The ESPACE Group study result support the experimentation and general conclusions previously arrived at by speech-language pathologists and theatre professionals working over more than ten years with the Aphasic Theatre. However, the study does not answer all the questions the authors hoped for. The Aphasic Theatre practitioners know that its efforts and results are more and more recognized as an alternative solution to the isolation and loss of self-esteem encountered by aphasic people. When it started its activities in 1992, it was the only institution to use drama and theatre to assist aphasic people. When it went to Nantes, France, in 1995 to present its first play, the new and innovative approach was quickly adopted in that country. The association of aphasic persons for the department of Ile de France near Paris formed its own theatre group, GAIF. At the invitation of French theatre group, the Aphasic Theatre presented in 2005 a play at the Comédie-Française. Aphasic groups in other countries, example Brazil, have also formed theatre groups and have followed the example of the Aphasic Theatre based in Montreal.

The authors believe that a more advanced study is warranted in order to gain more conclusive data and results. A new study should collect data over a longer time frame so as to better follow the adaptation experience and to better measure more meaningful long-term results. Also, a higher number of participants in each group would be invaluable to collect more data for each step of the workshop and play processes and specifically how the aphasic persons evolve.

The Aphasic Theatre and the professionals involved have done groundbreaking work since 1992. Its success in providing hope and opportunities for aphasic people is now recognized internationally. It is well established to pursue its mission of informing the public of the aphasic person's condition as well as presenting theatrical works casting aphasic persons.

Figure 3. *Métronome, directed by Richard Gaulin.*

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Passages – a 3D artistic interface for child rehabilitation and special needs

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ABSTRACT

Passages is an immersive, multimodal, user-controlled artistic interface. It consists of a three-dimensional interactive Virtual Environment that can be created, explored and interacted with in real-time. The installation has been exhibited in Grenoble, France, during the ENACTION_in_Arts conference (November 19-24, 2007) and in Pisa, Italy, during the Beyond Movement workshop (December 17-21, 2007). This paper outlines the design of the artistic installation *Passages,* and its potential in the field of rehabilitation.

1. INTRODUCTION

An outgrowth of the Computer Graphics research field, Virtual Environment (VE) technology has today become a fully independent research topic. VEs are simulated environments generated by a computer with which human operators can interact through different sensory modalities. Real-life applications of VE technology are an increasingly emergent phenomenon, although still in very specialized contexts. There are some fields that have shown a superior receptivity to VE concepts and techniques, the best example being applications of virtual prototyping in the Industrial sector, and in particular collaborative design, product presentation and training.

In the medical sector VEs are commonly used in surgical simulation tasks, medical imaging and neuroscience. One of the most promising medical applications for VE technology is rehabilitation. In this case devices and interaction modalities may present very different features depending on the therapy or the pathology being dealt with. In fact the great flexibility of Virtual Reality (VR) represents one of its great strengths, allowing the most disparate therapeutical needs to be addressed and adapted to the special needs of some users.

Indeed, VR is increasingly used to treat pathologies like autism (Gillette et al, 2007), phobias (Carlin et al, 1997) (Powers and Emmelkampa, 2008), brain lesions and neurological speech disorders (Rizzo, 1994). Such systems are designed in order to establish an efficient "interface" between patient and therapist, allowing the latter to define protocols and measurements which will be subsequently used to perform a quantitative evaluation about a patient's progress. Usually these systems are based on mainly visual protocols, using a range of different types of displays. These may be either standard screens or immersive technologies like head-mounted displays and/or CAVEs (Cruz-Neira et al, 1992). Such is the case in phobia treatments, for example. In the field of motion rehabilitation, however, force feedback devices like haptic interfaces and exoskeletons are also used heavily. These devices are robots able to exert controlled forces upon the user, to enable perception of the VE by means of touch. The generated forces may also be calibrated in order to assist or impede the patient's motion while performing a specific exercise, depending on the type of therapy. There are several types of robots for this purpose, depending on the functionality required (i.e. allowing planar or three-dimensional movements) or the interaction mode (the robot may be in contact with only one point of the patient, for instance a finger, or it may be completely wearable, etc.).

VE technologies are rapidly gaining traction in the fields of Art and Cultural Heritage as well, both for reasons of preservation and conservation as well as for educational purposes. Because VR allows for new perceptual experiences and research opportunities, it presents exciting possibilities for artistic expression and fruition, and therefore a platform for individual enrichment and cultural growth.

2. *PASSAGES*: INSTALLATION OVERVIEW

2.1 Technical setup

The *Passages* installation is composed of a stereoscopic projection screen, Infitec stereo glasses and a wand. The position and orientation of both the glasses and the wand are acquired by a long-range Polhemus electromagnetic tracker.

By moving the wand in space, the user can generate luminous traces into an immersive three-dimensional space, see Fig. 1. These traces are projected on the rear-projection surface (the powerwall), driven by two superimposed high resolution projectors connected to a PC rendering the virtual world. Real-time positional information of the user's eyes and wand are processed by the Polhemus system and passed to the rendering engine on the PC to generate the appropriate perspective for each of the user's eyes.

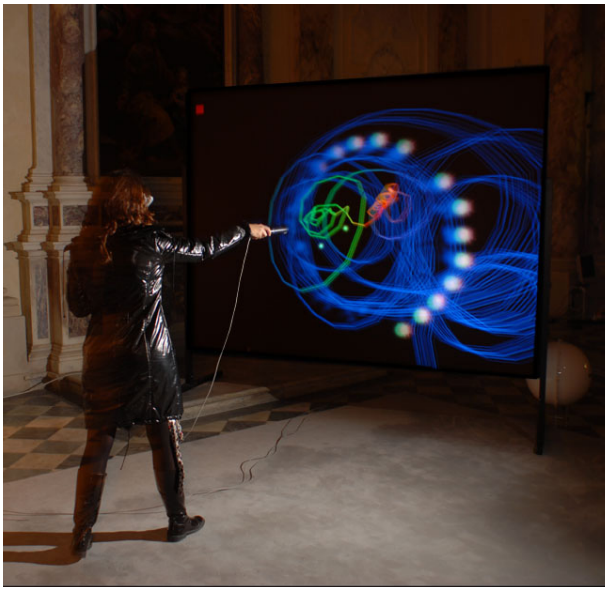

Figure 1. *User interacting with Passages.*

The environment is realized using XVR (eXtreme VR) technology (Carrozzino et al, 2005), a development framework targeted at VR application development. Supporting a wide range of VR devices (such as trackers, haptic interfaces, immersive rendering systems, etc.) and using a state-of-the-art graphics engine for the real-time visualization of complex three-dimensional models, XVR allows the development of applications ranging from simple 3D web presentations to advanced off-line VR installations. XVR applications are developed using a dedicated scripting language whose constructs and commands allow for the easy inclusion of 3D animation, positional sound effects, audio/video streaming, real-time physics and advanced user interaction. The *Passages* application software runs within Windows and its output is displayed full screen in Internet Explorer.

2.2 Expression through movement and gesture

Immersants in the installation expressively interact with an abstract environment centered on the concept of bodily exploration and enactive knowledge (Varela et al, 1991). As the user moves and traces his or her "passages" in the space through the use of the wand, luminous coloured lines are created that can be modified through further movement. The color of these expressive beams of light changes relative to their distance from the numerous sparkling lights that move in the three-dimensional space, as shown in Fig. 2.

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Figure 2. *Installation output.*

The user can create architectures of light and colour that always move relative to his or her perspective; the traces can be interrupted with a specific gesture (a quick shake of the wand) or can be carried on by other users. This virtual world is designed to evoke an emotional experience of awe and discovery, where the user's gesture becomes a direct form of multimodal composition.

In the two exhibitions mentioned previously, *Passages* has been experienced by numerous users, see Fig. 3, and has proven to be a powerful tool for creativity and bodily expression by providing a high sense of immersion and engagement. Indeed, the potential of Passages as an "Expression Interface" for rehabilitation was suggested during user evaluation by participants of the installation.

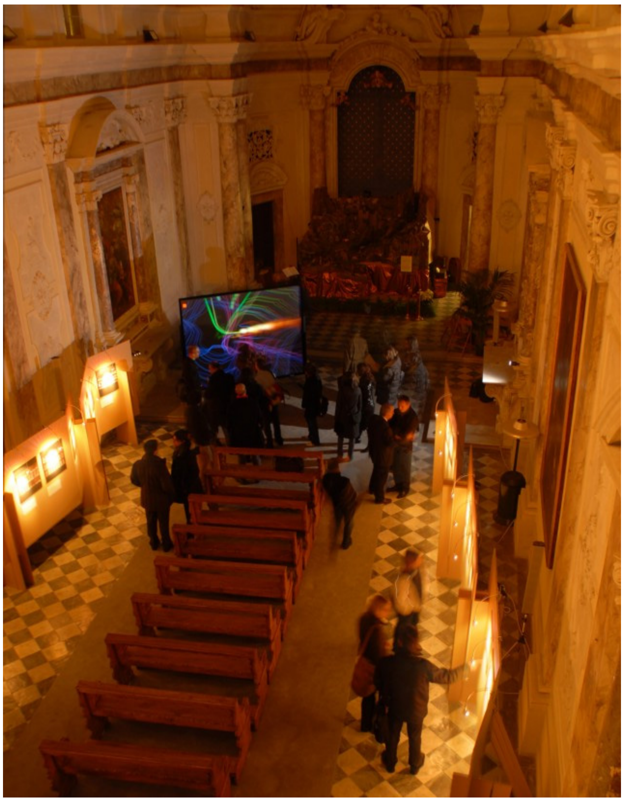

Figure 3. *Passages at Beyond Movement, Pisa, 2007*

3. ENACTION_in_Arts: AN EMPIRICAL EXPERIENCE EVALUATION

3.1 Enaction_in_Arts and ENACTIVE 07

The Enaction_in_Arts exhibition was particularly valuable opportunity for the evaluation of the experience, due to the wide visiting public and diverse typology of visitors. The Enaction_in_Arts exhibition was an open event organized in the framework of the Enactive 07 conference, promoted by the European Network of

Excellence ENACTIVE (*www.enactivenetwork.org*). The exhibition, featuring nine artistic installations, attracted over 900 persons. Among them, twenty percent were conference participants, forty percent were regulars of the contemporary arts, and the remaining sixty percent were members of the general public. The conference participants had a mixed background (Engineers, Computer Scientists, Philosophers) but as members of the Network (at date in its forth year) all of them were familiar with the themes of enactive knowledge, creativity's role in science, VR and related paradigms of interaction.

3.2 Methodology and results

Participants were provided with a very basic explanation of the installation setup, limited to instructions such as "wear the stereoscopic glasses" and "move your hand to trace a line with the wand". The user interacted for an average of 10 minutes with the installation, during which time more instructions were provided if the user expressed his or her intention to end the interaction without having performed all of the performable acts (i.e., "if you come closer to the stars the traces change their colour"; "if you quickly shake the wand, the coloured traces will all disappear"). The evaluation of the system was carried out through non-structured interviews during the interaction, allowing users to express their emotions and reactions to the installation as their knowledge of it grew. In this way qualitative research findings were gathered about the installation that provide an ethnographic basis for future iterations of the design of the system (Laurel, 2003).

It is interesting to underline the differences between the general audience and expert users (the conference participants). In general, the experts needed less instruction and were more active in exploring the VE autonomously. The main difference consisted in the fact that while the experts were immediately aware of the three-dimensionality of the space (and thus moved back and forth perpendicularly to the screen and not only in parallel to it) the general audience was much more limited to a two-dimensional spatial model. The most frequent "figure" performed by 3D-aware users was a spiral, that they traced and then entered within quickly. On the contrary, the favourite activity of 2D-users was writing. Furthermore, almost all expert users suggested rehabilitation as possible application field, especially for children.

4. POTENTIAL FOR REHABILITATION

The following discussion summarizes what has emerged from our consultation both with recent literature about rehabilitation, art and creativity, and from the suggestions of expert users.

As a tool for rehabilitation, *Passages* would be particularly suitable for children due to its playful and colourful aesthetics and its "magic-wand" interaction metaphor. Indeed, environments in which users have "immediate" control (through movement) over sensual feedback of suitably interesting content is both aesthetically pleasing and capable of providing much therapeutic value (Lincoln and E G Guba, 1985), as it provides individuals with a level of self-motivation and coordination that may not otherwise be expressed.

The interface, expressly designed to avoid imposing the user a specific task to accomplish, encourages a free bodily expression and space exploration. Navigation and spatial awareness are encouraged by the sparkling lights allowing colour modulation of the traces that motivate further action.

Playful and active engagement can potentially improve an individual's recall of spatial layout and orientation, provide motivation for free-body movements among children with motor disabilities and incentive for further self-initiated actions (Standen et al, 1996). Evaluation and training of spatial awareness in children with physical disabilities could also be provided by an unbounded interaction of this nature.

The actions of users as they interact with one another over time create a luminous landscape of motion, since the wand can be passed from one user to another. This feature represents an interesting potential for children affected by intellectual disabilities such as Autistic Spectrum Disorders (ASD), since it encourages a form of communication, mutual coordination, creative co-presence in the virtual space and social behaviour.

The virtual space in *Passages* is totally dependent on user-driven gestures and motions, and does not aim to represent an architecturally understandable space or a familiar environment. Precisely this "abstractedness" (Small, 1996) can be seen as an opportunity of positive interaction for disabled children. Thus the light and colour landscapes, despite their abstractedness, provide the user with a visual pleasure that can be associated to 'aesthetic resonance' - a situation where the response to an intent is so immediate and aesthetically pleasing as to make one forget the physical movement involved in the conveying of the intention (Brooks et al, 2002).

Passages is an artistic interface that goes beyond icons, symbolism and constraining human-computer interface metaphors to become both fluid and embodied. This approach builds on a recent trend in philosophical and cognitive models of the human mind that understands all linguistic and iconic knowledge as "embodied" action (Lakoff and Johnson, 1999, and Valera et al, 1991). This interaction paradigm expressly avoids traditional mouse/keyboard usage, allowing accessibility by children with physical disabilities who are unable them to perform fine motor movements such as those required by most computer interfaces.

5. CONCLUSIONS

In the future, improvements to the *Passages* installation itself will be incorporated and evaluated through further scientific research. Given the predictions of experts today (MacIntyre and Feiner, 1996; Cadoz and Wanderley, 2000), the efficiency of gesture learning and expression is likely to have widespread implications on the future of human-computer interaction. For rehabilitation environments in particular, performed data could be mined by an intelligent system to understand which aspects of movement are similar and how patients' gestures evolve through use. Opportunities incorporating real time machine learning and interactive human/system interface didactics will be fascinating to apply in a networked environment where a variety of users collaborate to teach the system how to structure an abilitation environment that surpasses the capacities of the individual therapist.

Passages is an ongoing project exploring the expressive potential of multimodal environments. In conclusion, it is an artistic user-friendly interactive environment that encourages and motivates social interaction and spatial exploration. The added value of being "fun" to interact with (as noted by the majority of the users who experienced it), could well be a deceptively simple yet remarkably valid resource for special needs patients (Lakoff and Johnson, 1999) and rehabilitation in general.

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Cognitive effects of videogames on older people

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ABSTRACT

In these days the percentage of older people in the population is growing worldwide. It is therefore urgent to decrease the morbidity resulting from biopsychosocial losses associated with old age. The preservation and recovery of cognitive functions and of physical, psychological and social autonomy are provided through new mental and physical activities. As have other activities, the use of video games has shown benefits for this ageing population, in particular at the cognitive level. Although there are only few studies which studied this videogames' application. In this study we studied the cognitive effects of videogames on the elderly people. And we also studied these effects on self-concept and on the quality of life. The instruments used are the Cognitive Sub-scale of Alzheimer's Disease Assessment Scale, the Clinical Inventory of Self-Concept and the WHOQOL-Bref. The study involved the participation of 43 elderly people distributed between 3 experimental conditions (n = 15 used videogames, n = 17 relaxation and n =11 had no intervention). There were two moments of assessment, before the intervention (Pre-test) and after eight weeks of it (Post-Test). Old people shows to be able to use videogames as well as to like to use it. Although they faced some difficulties using key board and mousse. They show to prefer games without time challenge and without fast and exact movements. They also show to prefer videogames with a real story behind the play activity. It was found that the videogames participants showed a decline in cognitive deterioration from the pre to post intervention tests (t (14) = 3,505, p =. 003, r = .68), unlike the control groups. The self-concept deteriorated up significantly under relaxation condition (t (16) = 2.29, p = .036, r = .50) and on passive control group (t(10) = 3.44, p = .006, r = .74). The quality of life did not show any differences from the start to the end of the study. Nor were any correlations found between the time of use of videogames and larger effects. The mediator effect of self-concept on differences obtained in the ADAS-Cog (rS = .57, p = .014) and in the ICAC (rS = -.47, p = .039) was confirmed. In sum, the results show that the use of videogames leads to the improvement of cognitive functioning and to the maintenance of the self-concept and the quality of life of elderly people. They also suggest that the higher the self-concept, the better are the cognitive effects achieved.

1. INTRODUCTION

The improvements of hygienic conditions and medical knowledge led to the individual aging enlarge. The twenty-first century are even called of the aging century, because it is characterized by the abrupt increase in the proportion of elderly population.

United Nations (2001) expects that in 2050 the elderly population will represent 15.6% of the world population against 21% of young adults.

It is consensual that elderly population is more vulnerable to bio psychosocial losses, despite the fact that the aging process is very heterogeneous. At a physiological point of view, every system can reflect their organs aging. There are several changes in the nervous system: neurotransmitters levels changes, the brain atrophy, neuronal cells modifications, oxygen and blood flood decrease (Kaplan and Grebb, 1997). There is even evidence that the brain atrophy is linked to age-related cognitive decline (Albert and Killianny, 2001). And the age-related cognitive decline (especially the moderate decline) is related to psychological symptoms as clinical depression (e.g., Forsell, Jorm and Winblad, 1994), low self-concept and quality of life. The rest of the related aging losses also contribute to these psychological symptoms. These losses are especially social

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losses. During the aging process elderly people lost significant others. These losses are related to deaths, to the end of professional relationships and to the distance of others (which is more difficult to overcome) (Giddens, 1997). Consequently, older people are submitted to a loss of social support. And these losses are intensified by *ageism* (the word Ageism was created by Butler (2005) based on words to designated discrimination against black people (racism) and against women (sexism). It is related to prejudices against older people).

Regarding cognitive decline, many studies have demonstrated that certain cognitive functions diminish with increasing age. Information processing speed is compromised, as is memory, verbal fluency, efficient consolidation on newly learned information and executive functions such planning and behavioural organization (Hooren et al, 2007).

At the same time, several studies argue that Information and Communication Technologies (ICT) have benefits to the older people. It is argued that TIC can improve social support (e.g. Wright, 2000; White et al, 1999), cognitive functioning (e.g. Bond, et al, 2001), quality of life (e.g., Leung and Lee, 2005; McConatha, McConatha and Drmigny, 1994) and diminish depressive symptoms (e.g. Whyte and Marlow, 1999). There are also studies that refer the benefits of videogames, which are specific ICT instruments. Visual improvement (Green and Bavelier, 2006, 2007; Risenhuber, 2004), spatial visualization (Subrahmanyam and Greenfield, 1994), reaction time (Bialystok, 2006), visuo-motor coordination (Griffith et al, 1983) and quality of life (Leung and Lee, 2005) are some of the benefits verified. The videogames' studies with older people verified several benefits too, although there is only few studies until now. The benefits achieved with videogames by older people are: reaction time(e.g., Dustman et al, 1992; Clark, Lanphear and Riddick, 1987; Goldstein, 1997); cognitive functioning (Farris et al,1994), intelligence (Drew and Waters, 1986), visuo-motor coordination (Drew and Waters, 1986), attention and concentration (Weisman, 1983), self-esteem and quality of life (McGuire, 1984; Goldstein, 1997). Green and Bavelier (2006) adverts that a massive increase in the amount of dopamine released in the brain was indeed observed during video game play, in particular in areas thought to control reward and learning. They also adverts that the role of this surge in dopamine and its implications are not currently well known, but work in rats suggests that dopamine may be important in the modification of the brain following perceptual training.

The aim of this work is to test the acceptance of videogames of older people and their ability to use it. Our purpose is also to identify the factors which contribute to their acceptance level. Simultaneously we will evaluate the cognitive effects of the videogames use on older people, as well as, the effects on their self-concept and quality of life. We also evaluate the mediator effect of self-concept on cognitive results achieved. We believe that older people are able to use videogames and that instruments have beneficial effects to them. We expect that higher the self-concept higher will be the beneficial effects.

2. METHOD

2.1 *Sample*

Participants were 43 people (10 man and 33 woman). They are all Portuguese and belongs to a residential homes to older people (26 are resident, 8 are daily frequent and 9 are activities frequenters). Mean age of 78.33 (SD= 8.002, min=65, max=93).

Participants presented the following inclusion criteria: 65 years old or more, inexistence of aphasia, hearing and visual severe deficits or behavioural and perceptual disorders. They maintained the psychopharmacological therapy during the experiment period and before two months of its beginning. All of them gave their informed consent. The study followed the ethical standards of the American Psychological Association (APA, 2001).

On the beginning of the study we randomised the participants for 2 groups: experimental group (with videogames) and control group (with relaxation sessions). Although, some of them could not participate in the 2 kinds of activities, so we opted for to have 3 groups: experimental group (videogames – n=15), active control group (relaxation sessions, n=17) and passive control group (without experimental treatment, n=11). There is not significant statistical differences between the 3 sample groups regarding the age ($F=.340$, $p=.714$), the sexual genre ($\chi2(2)=4.38$, $p>.50$), the education level ($\chi2(6)=5.5$, $p>.50$), the previous occupational area ($\chi2(12)=20.74$, $p>.50$) and the marital status ($\chi2(8)=4.47$, $p>.50$).

2.2 *Instruments*

2.2.1 Measures. There are 2 evaluation stages: pre and post-tests. Each stage encloses different instruments full-fill. The instruments used are: a demographic questionnaire (age, occupational area, educational level, marital status, physical and emotional disorders, medication and time of use); the cognitive part of the Alzheimer Disease Assessment Scale – ADAS-Cog (Rosen and Mohs, 1984; Portuguese version: Guerreiro, 2003); The clinical self-concept inventory – ICAC(Vaz-Serra, 1986); The World Health Organization Quality of Life Questionnaire – WHOQOL (WHOQOL Group, Portuguese Version: Vaz-Serra et al, 2006). In the first assessment the participants also full-filled the consent form and in the final assessment they answered to questions about the sessions satisfaction and about the occurrence of life parallel major problems. The instruments used showed good psychometric characteristics in our sample. The most important psicometric characteristic in our study (a pre and post test design) is the test-retest correlation, which is high in ADAS-Cog ($r=.83$, $p=.000$), in ICAC ($r=.75$, $p=.000$) and lower in the WHOQOL-Bref ($r_S=.55$, $p=.000$).

2.2.2 Intervention Sets.

2.2.2.1 Videogames. The videogames was selected based on their cognitive stimulation capacities. We opted to use causal games because they involve very simple rules and play techniques, making them easy to learn and play (IGDA, 2006). Participants of the experimental group are submitted to 8 videogames sessions (one weekly). It was selected 7 videogames after we use several videogames with a pilot-participant: QBeez, Supper Granny 3, ZooKeeper, PenguinPush, Bricks, Pingyn and memory games. The QBeez game was referred by Nicole Lazaro (2006) as being a game with emotional capacities and subsequently with capacity to develop a high interest level on users. In our opinion this games can improve the attention-concentration, the processing speed, the procedural tasks, the work memory and gnosis. The Supper Granny 3 game involves the resolution of problems and consenquently the attention-concentration, processing speed, the executive functions, the work memory and the spatial orientation. The Zookeeper seems to be able to stimulate attention-concentration, processing speed, the procedural tasks, the work memory, gnosia, and temproral orientation (because it has time challenging). PeguinPush seems able to stimulate attention-concentration, processing speed, spatial orientation and executive functions. Bricks were widely referred for being an exercise of knowledge of physic. We believe that it can exercise the attention-concentration, the processing speed, the procedural tasks and the work memory. Pingyin can improve attention-concentration, process speed, working memory, the procedural tasks and temporal orientation. The memory games can improve memory functions and also attention-concentration, process speed, gnosia and temporal orientation (in which there is time challenge).

2.2.2.2 Relaxation Session. The active control group was submitted to 8 relaxation sessions (one per week). The relaxation method used was the Jacobson's progression muscular relaxation training.

2.2 Procedures

After the videogames selection we try them in a pilot-participant, who selected the definitive 7 videogames which are the most adequate to his use. The participant-pilot was similar characteristics to the 43 study participants (the inclusion criterions). We also take advantage of his participant-pilot pre-study to test all the procedures to comply with during the assessment and intervention session. Then we selected the study participants through the clinical files analysis to confirm the inclusion criteria. After this selection we did a first interview in which the general aim of the study was introduced (to study the older people in two activities – we opted for being very general in the purposes presentation in order to avoid induce a bias of participants' behaviour (Hawthorne Effect)) and was full-filled the measures (Pre-Test). Then we randomised the participants by the experimental conditions. During 8 consecutive weeks the participants was submitted to the experimental conditions (videogames or relaxation sessions). And finally, we did a last interview to fulfill the second assessment of the measures (Post-Test) and to evaluate how the participants feel about the experiment and also to know if there are some life events relevant during the experiment period.

It is important to remark that as the participants did not have computer literacy, we had to do training on the beginning of the first session. The training consists on an introduction of the mouse and keyboard functioning and it was a duration of approximated 5 minutes (depend on the participant acquisition satisfaction).

In the first videogame session it was also presented all games to the participants, who can choose which they would which to play. In the following sessions we asked if they want to see all the games again or if they know which they wish to play already.

In all videogames' sessions the participants didn't have a period limited to use the games, they can use it how long they wish. During the sessions we give them reinforcements ("Well done") and prompts ("Ok, lets see what you have to do now, you will find out.").

3. RESULTS

3.1 *Quantitative Results*

In the experimental condition (videogames condition), participants presented greater cognitive deterioration at the pre-test assessment (M=17.60, SD=7.68) than at the post-test assessment (M=14.20, SD=5.98). This difference was a statistical significant decrease at ADAS-Cog[1] (t(14)=3.505, p=.003, r=.68). And this effect is high, because it explains 46% of the total variance. In opposition, participants at the control conditions presented a non significant increment (see table below).

Table 1. *Pre and Post-Tests ADAS-Cog Results at each condition.*

	Videogames Group			Active Control Group			Passive Control Group		
	Mean	D.F..	St. D.	Mean	D.F..	St. D.	Mean	D.F..	St. D.
ADAS	17,60	14	7,68	18,24	16	7,96	17,18	10	7,73
ADAS_pos	14,20	14	5,98	19,94	16	9,22	19,82	10	13,26
t-test	3,505(*)			-1,69			-1,28		
p	.003			,109			,230		

* significant at the 0.05 level

Table 2. *Pre and Post-Tests ICAC Results at each condition.*

	Videogames Group			Active Control Group			Passive Control Group		
	Mean	D.F.	St. D.	Mean	D.F.	St. D.	Mean	D.F.	St. D.
ICAC	71,93	14	6,16	72	16	6,48	73,45	10	4,91
ICAC_pos	71,47	14	5,97	69,29	16	6,82	69	10	7,5
t-test	,49			2,29(*)			3,44(*)		
P	,64			,036			,006		

* significant at the 0.05 level

Table 3. *Pre and Post-Tests WHOQOL-Bref Results at each condition.*

		Videogames Group			Active Control Group			Passive Control Group		
		N	Mean Rank	Sum of Ranks	N	Mean Rank	Sum of Ranks	N	Mean Rank	Sum of Ranks
Quality of Life G post - Quality of Life G pre	Negative Ranks	5[a]	6,00	30,00	11[a]	7,45	82,00	2[a]	3,00	6,00
	Positive Ranks	5[b]	5,00	25,00	3[b]	7,67	23,00	3[b]	3,00	9,00
	Ties	5[c]			3[c]			6[c]		
	Total	15			17			11		
Z Wilcoxon Signed Ranks Test		-,262[d]			-1,934[d]			-,447[d]		
Asymp. Sig. (2-tailed)		,794			,053			,655		

a. Quality of Life G post < Quality of Life G pre
b. Quality of Life G post > Quality of Life G pre
c. Quality of Life G post = Quality of Life G pre
d. Based on positive ranks.

[1] At the ADAS-Cog, lower the total result, lower the cognitive deterioration level.

Regarding the results achieved with ICAC, it was verified a decrease of self-concept in all the conditions, although the videogames conditions was not a significant decrease. In respect to quality of life, there wasn't any significant statistical differences (See Table 3). Differences between pre and post tests of the measures used in our study didn't showed to be significantly correlated to the time of use of videogames as we can see in the Table 4 below.

Table 4. *Correlation between time of use of videogames and differences achieved in dependent variables.*

		Dif. ADAS	Dif. ICAC	Dif. WHOQOL
Time of Use				
	Correlation	-.130[a]	.071[a]	,334[b]
	Sig. (1-tailed)	,257	,362	,112
	N	15	15	15

a. Spearman Correlation

b. Pearson Correlation

The results obtained in our study confirm that there is a positive correlation between the initial ICAC overall result and the differences achieved at ADAS and ICAC. There is not however a significant correlation with the results of the WHOQOL.

Table 5. *Correlation between Initial Self-concept and differences achieved at the Dependent Variables*

		Dif. ADAS	Dif. ICAC	Dif. WHOQOL
ICAC_Total	Correlação	,566(*)[a]	-,469(*)[a]	,234[b]
	Sig. (1-tailed)	,014	,039	,201
	N	15	15	15

a. Spearman Correlation

b. Pearson Correlation

The statistical tests also allow us to assure that the demographic variables didn't interfere in the differences achieved. Sex genre do not influence the differences achieved at ADAS-Cog ($U=148$, $p>.05$), at ICAC ($U=165$, $p>.05$) and at WHOQOL ($U=155$, $p>.05$). The educational level also didn't influence the results achieved at ADAS-Cog ($H(3)=.62$, $p>.05$), at ICAC ($H(3)=3.45$, $p>.05$) and at WHOQOL-Bref ($H(3)=2.5$, $p>.05$). Neither did the previous occupational area: ADAS-Cog ($H(6)=5.78$, $p>.05$), ICAC ($H(6)=1.64$, $p>.05$) and WHOQOL-Bref ($H(6)=4$, $p>.05$). As well as, the marital status didn't influence the results: ADAS-Cog ($H(4)=4.37$, $p>.05$), ICAC ($H(4)=3.14$, $p>.05$) and WHOQOL-Bref ($H(4)=8.28$, $p>.05$). Age didn't show any influence on the differences achieved at ADAS-Cog ($rs=-.2$, $p>.05$), at ICAC ($rs=.04$, $p>.05$) and at WHOQOL-Bref ($r=-.1$, $p>.05$).

3.1 *Qualitative Results*

During the experiment we registered also qualitative observations data.

The answers obtained to the final questionnaire, regarding participants satisfaction with sessions, show us that only one participant thinks that a part of the session are not very adequate to his cognitive skills (ADAS-cog tasks). He thinks that it is to people with worse cognitive difficulties. It was explained that the tasks have to be the same for all participants despite the cognitive skills (because it is a scientific study). The other participants think that the sessions was adequate.

We also observed that 2 women didn't want to participate in videogames sessions even before to see it. One did not want because she never had liked games, even traditional ones. The other women never had liked any kind of machines.

We observed that all of the videogames participants are able to use the computer after a brief introduction of use (5 minutes). Despite that their majority feels initially anxious about the computer use. Before the computer use they said that they are not able to do it and similar sentences. During the videogames use, participants expressed them self with sentences as “It is very funny!”, “Can you give me this to put in my grandchild computer to allow me to play more?” and “This is really a good entertainment!” During the use it was also observed another kind of contentment expressions as laughter, especially when they achieve the videogames purposes. Although we observed that they faced some limitations on computer use. They do not feel very confident in mouse and keyboard use, so they use it low and sometimes it is hard to them see the cursor.

It was interesting to observe that some videogames are more chosen than other. In Table 6 below we present a decreasing list of videogames preferences. The last three was equally chosen by the participants.

Table 6. *Videogames Used by decreasing order*

	QBeez	
	Super Granny 3	
	Memória	
	Pingyin	
Zoo Keeper	Bricks	Penguin Push

Regarding this observation the first two games are played without time challenge. The memory games chosen by participants are all without time challenge too. They demonstrated very interest for the Pingyin, because it is a videogame about the climate current world problems, but they give up to use it because they could not handle with the time challenge. Zookeeper has the time challenge difficult too and does not elicit as much interest as Pingyin did. Participants shows difficult to handle with the precision and fast of the movements. Despite they can manipulate the Penguin Push, they feel a little boring during its use.

It was also observed that some participants complained about excessive tears in the eyes during the game playing.

4. CONCLUSIONS

The results achieved in this study supports that older people are able to use computers and that the videogames use can improve their cognitive skills. The results also supports that the videogames use maintain the self-concept and the quality of life of older people. Although it does not support that if older people play it during more time they can achieve better results. It seems, however, that when they have higher self-concept, they can achieve more cognitive improvements.

Our results are according the previous studies regarding cognitive effects of videogame playing by older people. We believe that if the intervention period was extended (longer than 8 weeks), the improvements would also have higher influence on the self-concept and quality of life.

We also observed that women show fewer predispositions for videogames playing than men as it is widely found. Any man refused to try videogames, in opposite to two women.

Despite the ability of older people to computer use, they have some anxiety about it and there is some interface limitations to this population too. We believe that it is necessary to demystify the prejudices about aging and about the use of computers by older people, in order to reduce the anxiety verified. At the same time it is necessary to improve ICT design to adequate it to this population. We think they would benefit with tangible interfaces as touch screens or Wii equivalents. We also think that they avoid videogames with very fast and precise movements and with time challenge. We think that our qualitative results also let us to conclude that they prefer videogames with a real and meaning story behind it.

We can not retire any conclusion about the tears effect observed, because we do not have how to know if it is related to the therapeutic visual effects referred (e.g. Green and Bavelier, 2007) or, in the other hand, if it is just related to a visual effort to see the videogames interfaces. This would be object of future research.

Our study would be better if we have a bigger sample, although it has already more than the previous ones. We hope that this study can have practical implications in older people daily living and in future research.

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Providing disabled persons in developing countries access to computer games through a novel gaming input device

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ABSTRACT

A novel input device for use with a personal computer by persons with physical disabilities who would otherwise not be able to enjoy computer gaming is presented. This device is simple to manufacture and low cost. We describe the constituent parts of this device. A collaboration gaming application especially designed for this input device is given in brief.

1. INTRODUCTION

This paper's contribution is the description of an input device suitable for use by people with gross motor skill problems. The device can be manufactured at low cost.

A superficial survey of available personal computer (PC) input devices for the disabled will show that these are mostly well designed, but expensive. In developed countries where state subsidies reduce the financial burden for the disabled, this is less of a problem. However, in developing countries such subsidies either do not exist, or are minimal. The input device we present in this paper is simple to manufacture. It is quite feasible for the local community handy-man to construct it from a variety of materials. These materials include sheets of ply-wood or acrylic. A modified commercial joystick, magnets, and magnetic sensors are the main components of our input device (SlideStick). The magnets and magnetic sensors are commonly used as intrusion sensors in homes and offices, making them readily-available items. Electrical contacts of the magnetic switches are wired in parallel to the joystick switches. The stick usually used when manipulating the commercial joystick can optionally be removed, resulting in an improved compact unit.

Figure 1. The *SlideStick tangible input device consisting of: (left) the modified joystick controller and (right) the slider assembly.*

2. SYSTEM OVERVIEW

The system consists of up to four SlideSticks (Figure 1) connected to the Universal Serial Bus (USB) ports of a PC. Gaming participants each operate one SlideStick to collaborate in accomplishing a task. A player operates only one SlideStick. A player manipulates the slider using either the hands or feet.

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3. HARDWARE

A SlideStick consists of two components; these are (a) a mechanically robust slider assembly and (b) a modified joystick controller. An electrical ribbon cable connects the switches embedded inside the slider assembly to the modified joystick controller. Sensor closure events emanating from the slider assembly are made available to the software through the joystick USB interface.

3.1 Mechanical Components

The frame of the slider assembly consists of a magnet sub-assembly and a number of layers. The slider assembly is approximately 100cm long, 15cm wide and 5cm high, and constructed by combining individual layers into a single unit (Figure 2). Five magnetic switches are mounted in a linear fashion onto a base. The player activates the magnetic switches by sliding a permanent magnet across the switches. Movement of the magnet sub-assembly is physically constrained to a single linear dimension. A number of spacers separate the top and bottom layers. Within this space, the magnet sub-assembly moves freely. Yellow self-adhesive tape is attached to the magnet sub-assembly and is visible through the triangular notches of the slider assembly top layer. This provides an additional visual cue of the magnetic sub-assembly's position to the player. The magnetic switch contacts close as the magnetic sub-assembly moves over the sensor.

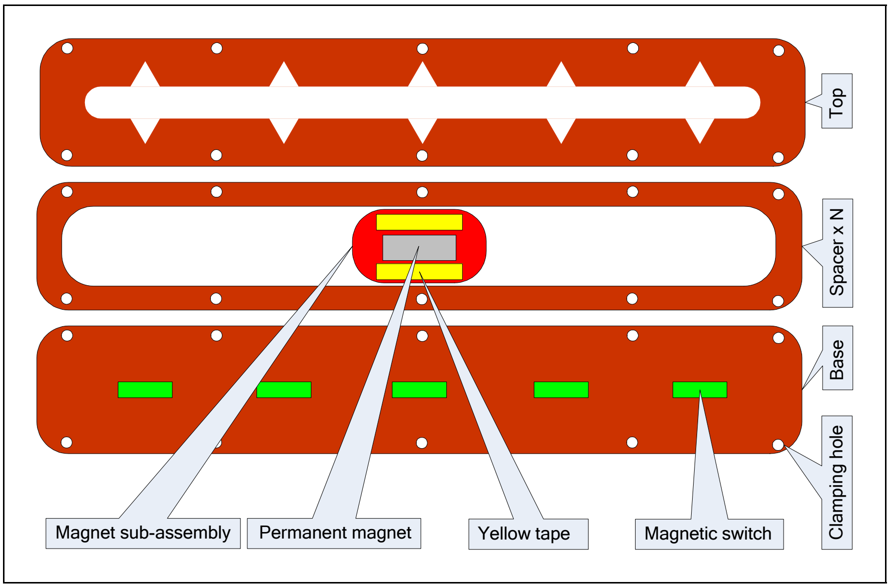


Figure 2. *Engineering diagram of the SlideStick slider assembly. The slider mechanism can move horizontally, closing the magnetic switches as it passes over them.*

3.2 Electronic components

The four commercial joysticks we modified each contain two analogue sensors to detect X- and Y-axis movement. In addition to the analogue sensors, the joysticks also contain a "hat" switch assembly and five discreet switches spatially distributed across the joystick enclosure. Our input device only makes use of the five spatially distributed switches. The two analogue sensors and "hat" switch are not used in our design.

Our modification requires the addition of five magnetic switches in parallel to the five spatially distributed switches in the commercial joystick. This requires the partial dismantling of the joystick to trace the connections of the switches on the circuit board. Five connections, one for each switch respectively, plus an additional common connection are routed using ribbon cable from the joystick to the slider assembly.

4. SOFTWARE

4.1 Overview

We have developed a simple gaming application (Figure 4) which encourages player collaboration. The game allows the players to colour in a picture using four SlideStick controllers.

The game makes provision for four players to participate in the colouring in process. Three players control the red, green and blue (RGB) colour mixture. The fourth player selects which part of the displayed picture should be coloured. Scrollbars on the sides of the gaming screen provide additional feedback to the players. In addition, a frame around the plying area displays the current RGB colour mixture. This is the colour that will be used to colour the selected area.

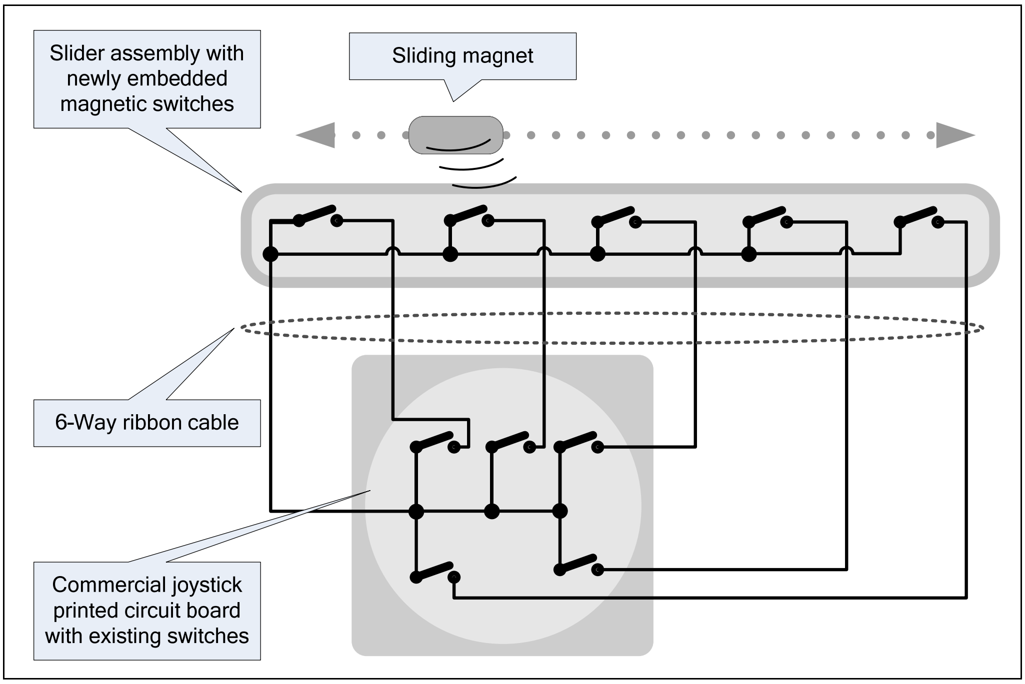


Figure 3. *SlideStick electrical diagram showing the added switches. The sliding magnet closes the magnetic switches as it passes over them.*

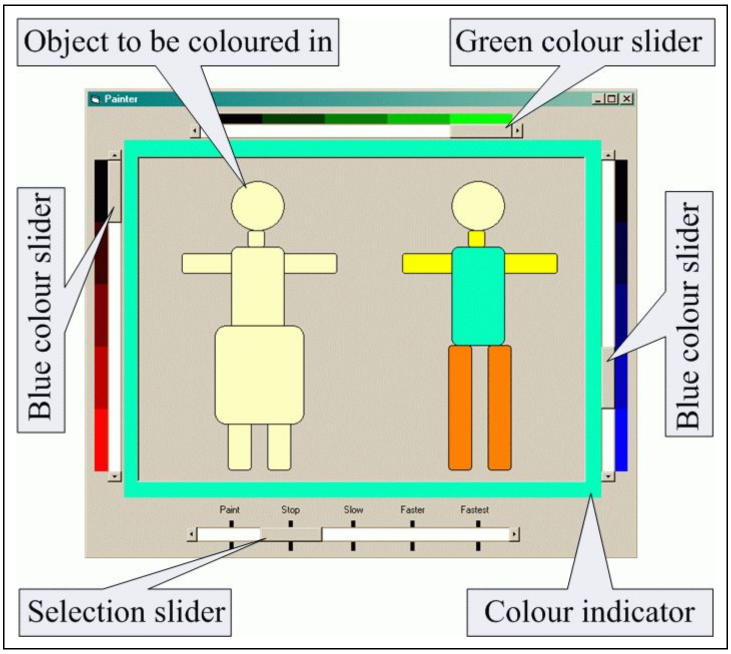
The gaming application "Painter" is written in the Visual Basic 6, service pack 5 computer programming language. Painter is available as open source and the compiled application is available for download [Painter, 2008].

4.2 Colour Selection

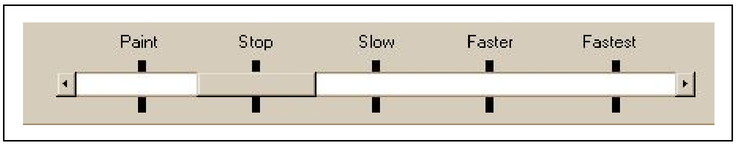
Three SlideSticks each respectively controls a component of the desired filling colour. This is done by moving the slider of the colour-selection SlideStick to select a shade of the colour assigned to that particular SlideStick. Colour shades range from dark to light (Figure 4 (a) left, top, right). One of five distinct colour values can be selected by each colour-selection SlideStick. This allows for a total of 125 potentially distinct colours that can be used for colouring the selected areas. The individual selections are then automatically mixed by the application software to give the resultant filling colour. The mixed result is made visible by changing the colour of the rectangular border around the central painting area (Figure 4 (a)).

4.3 Area Selection and Colour Application

The pictures in the painting application are composed of circles and rectangles. The user operating the object-selection SlideStick sequentially selects a circle or rectangle for painting. The slider on the screen (Figure 4 (b)) moves in unison with the object-selection SlideStick. Moving this slider would either sequentially select the painting object, or initiate the painting action using the current selected colour combination. The rate at which the sequential selection takes place depends on the slider position. The rate is adjustable between very fast, fast, slow, and very slow. The selected object flashes in the current selected paint colour. To apply the selected colour, the slider is moved to the paint position on the extreme left of the SlideStick.



(a)



(b)

Figure 4. *(a) The gaming application which was designed especially for use with the SlideSticks. Four players have to collaborate in order to successfully complete the task of colouring in the picture. (b) An enlarged view of the selection slider located at the bottom of the gaming application.*

5. TEST PREPARATIONS

The SlideSticks and gaming application were tested with the assistance of residents of a home [Qumi Homes, 2008] for intellectually and physically handicapped adults. Four persons were identified as testees; all over 50 years of age and having had no prior computer exposure. The testees' intellectual ages range from 7 to 10 years. One of the testees is a Cerebral Palsy case with moderate Ataxia – she is also wheelchair-bound (Figure 5, extreme right). The other three testees do not have any serious physical disabilities.

To improve the system's affordance [Norman, 1998, p9], we made some adjustments to the SlideSticks before testing with this group.

Figure 5. *Testees using the four SlideSticks that interface to the Painter computer application.*

The first adjustment was the use of coloured paper cut-outs (Figure 6). These were attached to the top surfaces of the three colour-selection SlideSticks. Five cut-outs of each colour were placed on the respective SlideStick. The darkest cut-out was placed on the extreme left (Figure 7, position 1) and the lighter shades sequentially to the right. These correspond with the shades shown in the application on the computer screen (Figure 4 (a) left, top, and right).

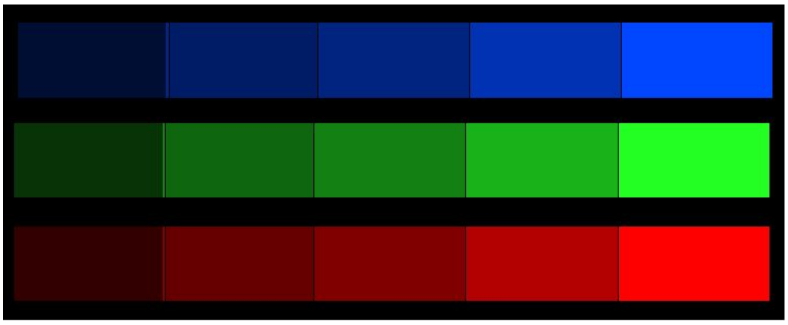


Figure 6. *Colour paper swatches before being cut and stuck onto the colour-selection SlideSticks. (top) Blue. (middle) Green. (bottom) Red.*

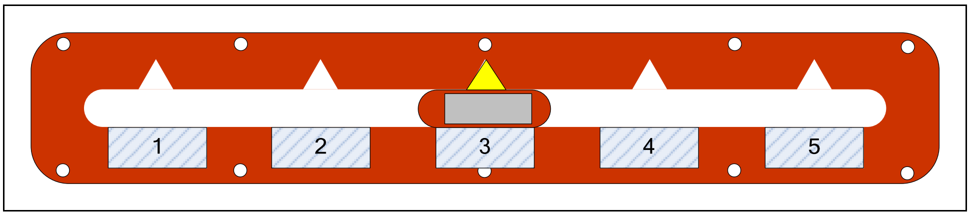


Figure 7. *Positioning of paper cut-outs on the slider assembly.*

The second adjustment we made was the addition of printed black-and-white pictures to the Selection slider. On the extreme left of the slider (Figure 7, position 1) we pasted a picture of a paintbrush. This indicates that a paint action will take place when the slider is in that position. In the remaining four positions (Figure 7, positions 2,3,4,5), a picture of an animal or an object was attached. These were placed sequentially in order of the speed each could attain in real life situations. They were a tortoise, an elephant, a motor car, and an aeroplane. The tortoise represented slow changes, the elephant faster changes, the motor car even faster changes and the aeroplane the fastest changes. These correspond to the actions depicted in Figure 4 (b). We also modified the Paint application by replacing the wording "Stop" (Figure 4 (b)) with "Very Slow".

6. RESULTS

Formal tests of the SlideSticks using the custom-developed educational BodyPingPong gaming application have previously been done with able-bodied children [Bekker and Kruger, 2006]. Informal tests with disabled children, using the same BodyPingPong gaming application have shown promising results.

Our latest testing was done with the aid of mentally handicapped adults. Interaction with the testees was verbal, no written questionnaires were used, and neither did we make written notes while interacting with the testees. In our discussions with the occupational therapist [Krause, 2008] associated with the mentally handicapped testees, we were told that the testees tended to want to please adults and therefore influenced how the testees responded to our questions. This was evident when we asked them what problems they have experienced with the test system during the week they have had unrestricted access to it. Collectively they denied that they had experienced any problems or that any system improvements were required. However, one testee (Figure 4, extreme right) later spontaneously mentioned to us in the presence of the other testees that they all needed more time to master the system. We did not get any unsolicited feedback from the testees.

7. CONCLUSIONS AND FUTURE WORK

We have presented an alternative input device which is suitable for use by people with certain disabilities. The input device can be manufactured by adapting commercial gaming joysticks. The required adaptation is simple and can be accomplished by an able-bodied person with limited technical experience. The high-volume at which commercial joysticks are manufactured, and the subsequent relatively low cost compared to other custom-built aids, makes this device a viable alternative to commercial aids.

By virtue of its large range of movement and low resolution, the SlideStick controller may be an ideal input device for people with fine motor control challenges. Our tests indicate that the input device can be manipulated by either the player's hand or the foot, making it potentially useful to people with physical disabilities.

We have developed this input device and the associated software as a concept demonstrator. The software still lacks in several areas and future versions of the software will have the capability to use suitable bitmaps of the user's own choice as well as the ability to print and save coloured images.

SlideStick was developed with the specific purpose of testing the viability of a low-cost, community-manufactured input device, together with custom-developed software, for use by people in developing countries. As such the SlideStick emulates the sequential pressing of five buttons on a joystick and no other joystick functionality. SlideStick in its current form is not meant as a replacement for a commercial joystick but rather offers an alternative input mechanism for custom-designed applications.

Informal evaluations of SlideStick with the custom-developed gaming application indicate that the emulation of the joystick's "hat" switch would result in a better system. This option would open up other possibilities with existing commercial games – such as changing the player's point-of-view and movement in a game.

Our informal tests with mentally handicapped adults indicate that the interface device should be simplified, perhaps only using two input positions instead of the current five positions.

Formal tests are needed with the mentally- and physically disabled communities to properly evaluate the value which this input device can provide to these target groups.

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Qumi Homes, Home for intellectually handicapped persons. http://www.qumihomes.org/

Unintentional intrusive participation in multimedia interactive environments

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ABSTRACT

This paper presents data from two independent case studies, a 15 year old female with Cerebral Palsy and related profound and multiple learning difficulties and a 7 year old male with extreme behaviour associated with Autistic Spectrum Disorder. An audiovisual immersive interactive environment was developed to encourage creative interaction and expression from the participants. There were support workers present in both case studies and it is the interventions of these support staff which are the main focus of this paper. Results indicated that profuse but unintentional interventions from the staff may have distorted interaction with, dissuaded or diverted participants from meaningful engagements with the reactive feedback provided by the system.

1. INTRODUCTION

There is an expanding body of research into the uses of multisensory multimedia environments (MMEs), and their implementation in the (re)habilitation of people with intellectual and physical disabilities (e.g. Williams et al, 2007). These multisensory environments can vary greatly in design and content from the traditional *Snoezelen room* concept using lighting effects, colours, sounds, scents and so on, to virtual reality (VR) environments (e.g. Standen & Brown, 2005) and other environments incorporating state-of-the-art multimedia technology (e.g. Hasselblad et al, 2007). The author constructed a multimedia environment using various items of technology along with a graphical programming environment, *Eyesweb*©[1] that created visual and auditory feedback according to the gestures or movement of the person within the environment.

Within these environments, the participants' actions and interactions are usually the point of focus, enabling the participant to engage with and creatively connect to the content the medium/media provides. Often, where the participant has severe motor function or verbal communication impairments, a facilitator (often the researcher) can also be present within, or in close proximity to the active multimedia space. The facilitator provides the necessary scaffolding (Wood et al, 1976), such as placement of the sensors, or guiding limb movement to maximise the interactions of the participant. This paper discusses the external interventions of support staff in two studies of pupils with learning disabilities using the MME *Picturing Sound.* In the first study, the author acted as facilitator in close proximity to the severely disabled participant, in the second study, the author could facilitate by gesturing and verbal intervention. The system aimed to provide an environment where minimal external interventions occurred. This approach follows Ellis' work with the *Soundbeam*©[2] device and children with special needs (e.g. Ellis, 1995). Ellis stresses that his approach is non-interventionist as it '*allows children to operate from the inside – out, to resonate individually and personally with sound itself*' (Ellis, 1995, p.59).

This work is based on studies carried out over a period of several sessions in a special school. All of the pupils at the school had a range of physical and/or intellectual impairment from moderate to profound. It is the author's assertion that these people have much to gain in that they are the least independent of all society, and that these multimedia or virtual reality environments can stimulate independent creative activities and/or autonomy not possible in everyday situations or environments.

2. BACKGROUND AND PURPOSE

Many people with complex disabilities can live passive lives due to their perceived non-communicativity (e.g. Basil, 1992). They also often appear to demonstrate minimal spontaneous interactive behaviour (Carter,

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2002). A plausible reason for this is the increased dominance and 'directiveness' given by the mother or caregiver in early interactions due to the perceived non-responsiveness of the infant child (e.g. Pennington and McConachie, 1999), this can foster a feeling of 'Learned Helplessness' (Seligman, 1975). This 'Learned Helplessness' is a state whereby a person feels they have no control over their environment or situation and that they have no power to change anything, even if they could. Many studies however have shown assistive technology (AT), and associated multimedia environments to be motivating (e.g. Goldenberg et al, 1984).

According to Brooks and Petersson (2007) facilitator intervention is critical in successful sessions of ludic or non-formal rehabilitation sessions within multisensory environments where often, incidences of *aesthetic resonance* (e.g. Ellis, 1997; Brooks et al, 2002) occur. They state that an intimate knowledge of the participant allows for 'breathing spaces' within the session to allow reflection and choice-making (Brooks and Petersson, 2007). The author adds that this intimate or long-term knowledge of a subject is not always necessary as a precondition of a successful session when the sheer novelty to a new user generates full engagement in the system, often with profound results (e.g. Williams et al, 2007). What is necessary though is a learned awareness of, and sensitivity to subtle vocal or non-verbal communications or gestures that could convey meaning. With this in mind it is important to acknowledge that in research, for example action research, there is inevitably researcher influence in outcomes. This study takes the principles offered by action research to be its baseline, but that the facilitator intervention differs from other researcher influence thus; it differs in that it does not expect an answer to a predefined set of questions, it does not predict a set of outcomes and it marries the role of researcher and subject so they co-exist as components of the research. The facilitator however fundamentally intervenes only when absolutely necessary and this intervention is at a sometimes literal, sometimes metaphorical arm's length. The facilitator withdraws or steps back (Brooks and Petersson, 2007) at *any* possible opportunity to allow the user to control and experience the responsive environment for themselves.

3. METHODS

Initially, after Yin (1994) and Tellis (1997), a 4-step method of qualitative enquiry was adopted.

- Design the case study
- Conduct the case study
- Analyse the case study evidence
- Develop the conclusions, recommendations and implications

Further investigation into action research models however indicated that for this particular study, there appeared to be a shift towards researching 'with' the subject, rather than 'on' the subject in the MME as the other staff present, by their behaviour, became the focus of the data study, so a hybrid approach of case study and action research evolved.

3.1 System design

As this was a new exploratory study, children were selected by a contact at the school and observed using the *Picturing Sound* MME. The environment encourages the children to create sounds and images through camera-tracking technology. The system uses the *Eyesweb*© graphical programming software. The camera tracking captures gestures and converts these into visual and audio feedback. The gestural feed-forward triggers the multimedia components and this feedback can be seen to be intrinsically motivating for the participant, encouraging further movement and engagement (e.g. Azeredo, 2007). A sound-processed (Korg Kaoss pad[3]) microphone provided audio feedback; an Alesis® Airsynth[4] provided further audio feedback and an Aura Interactor™ (obsolete product) cushion was used to provide vibro-acoustic feedback (e.g. Skille, 1991).

The diagram illustrates a typical layout of the system, the capture camera converts movement into various data to trigger the visual and MIDI (Musical Instrument Digital Interface) feedback. School support staff were present at all sessions conducted and were asked to be passive observers whilst the pupils were in the 'interactive space' created by the camera scope. The complex nature of the physical or intellectual impairments of the pupils participating would deem this ethically correct and for health and safety compliance. Video footage of the pupils was recorded for analysis purposes after two qualitative methods, Ellis (1996) and Brooks & Petersson (2005). As well as illuminating examples of pupil interaction and engagement in the environment, the footage revealed instances where the interactions of the participant were 'directed' by support staff present. The results look at two examples of seemingly excessive interventions.

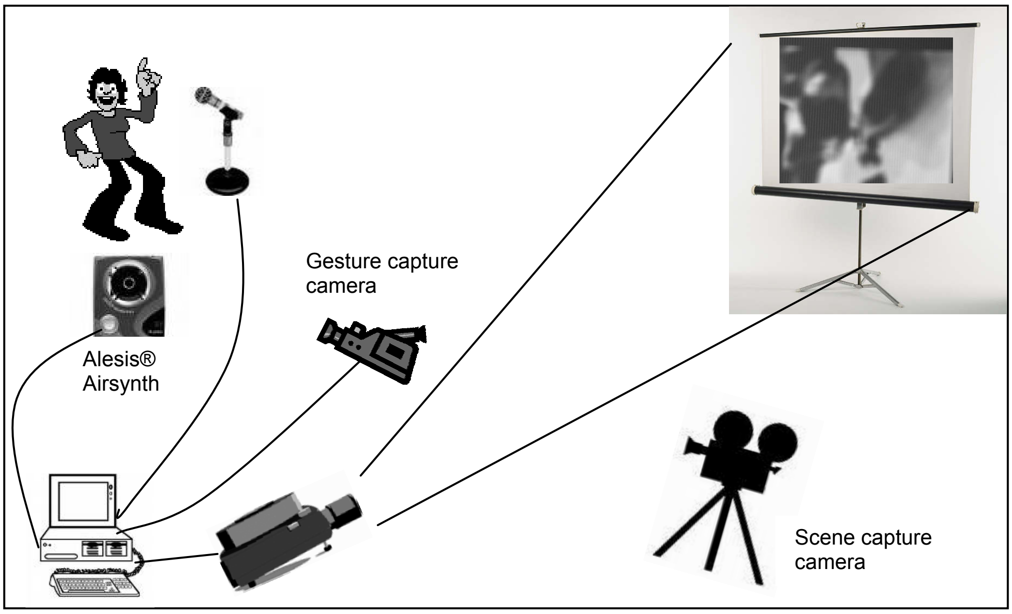

Figure 1. *Diagram of the system set-up.*

4. RESULTS

The results indicate that in both case studies, there were a significant number of commands, requests and directions from support staff, and also the author was party to some of these interventions, (however it must be noted the author was acting primarily as facilitator in the first case study, see conclusions). In case study 1, analysis revealed more than a hundred commands, directions and communications from the author and support staff. One reason for the proliferation of interruptions was possibly the curiosity of the staff towards the technology. It should be remembered that staff were briefed as to their passive role within the vicinity of the system.

Figure 2. *This picture illustrates the conversational background present during much of the session. Note the look of enjoyment of the activity on the participants face.*

In the first case study there were several main interventions and interruptions of note. The principal ones were:

- The members of staff who were present talking to each other audibly enough to warrant the label 'background interference noise'. This was probably due to the novelty of the system and the curiosity surrounding the technological equipment, therefore
- Members of staff calling out to the participant to interact with the processed microphone sound.
- Several members of staff calling out at the same time 'instructing' the participant to call another member of staff via the microphone.
- Staff commenting on the images the participant created through her (facilitated) movement, this was perceived as a distraction from the participant's engagement.

Further analysis revealed dialogues indicating support staff expressing 'ownership' of the communicative capabilities of the pupil. To expand on this suggestion one of the support workers stated that because the author was unknown to the participant, she would respond better to them than to the author. This cosseting approach would seem to close off or minimise any chance of widening the social interaction available to the person. The same participant's positive interactions within the same environment in a second session, reported in Williams et al (2007) would suggest the external interventions in this first session closed down any expressive intentions the pupil may have had. This observation highlights the importance of understanding the role of the facilitator in gently guiding or *scaffolding* (Wood et al, 1976) the experience of the participant rather than openly directing or initiating the interactions.

In the second case study, there was a single classroom assistant present during the session; again the assistant had been briefed to be as unobtrusive as possible during the session. The support assistant intervened more 30 times during a period of 4 minutes and 4 seconds with direct commands and gestures. The table below records indicates the frequency and type of intervention given and annotations based on the video analysis are given after the table. The Anvil software was used to encode the various interventions and the following table illustrates the frequency and type of intervention.

Table 1. *Frequency in minutes and seconds of spoken or gestural interventions from support worker.*

'07	Who's that?	'10	Freddy that's you!	'16	Look!	'35	Incoherent remark
'37	Look, where's your shoes?	'39	Look!	'41	Look at your shoes	'44	Sit
'47	Sit down	1'25	Sit there	1'41	Incoherent remark	1'55	No, sit down
2'01	Sit down then	2'11	Speaks with me	2'27	Look , that's you	2'36	No!
2'51	Sit down	3'00	Don't bite it (the mic.)	3'05	Don't bite it	3'11	Don't bite it
3'12	I tell the support worker it's ok for him to use the mic.	3'20	Moves hand off the mic.	3'26	Moves hand off the mic.	3'30	Wohoo!
3'33	Say, say car	3.35	Come on , say car	3'37	Touches face	3'40	Come on Freddy
3'43	Don't wet it	3'46	Say train	3'48	Wohoo!	4'04	Session ends

The table reveals a number of different kinds of intervention or interaction, some are very easily explainable, and others need further expansion for the lay reader.

The verbal interactions can be broken into;-

- **Positive directions** – these are interventions that could be seen as encouraging the participant to engage in the environment, e.g. 'Who's that?', 'Freddy that's you!', 'Say car', however video analysis suggests that the participant in the case study was already engaging with the visual feedback created by the environment or already exploring the sonic feedback created by the processed microphone sonic feedback.
- **Imperative directions –** these are interventions where the assistant directs or orders the participant to do something, e.g. 'Look at your shoes', 'Sit!'.
- **Negative directions** – interventions where the assistant directs or orders the participant not to do something e.g. 'Don't bite it', 'Don't wet it'.

The non-verbal interventions can be classed into two categories;-

- **Non-tactile –** interventions where the assistant moves into the *kinesphere* (Laban and Lawrence, 1974) of the user, which is the space surrounding the body that one can touch without moving. Figure 3. Illustrates the participant's unwanted interference from the support worker by his physical movement away from the assistant as she moves his hand away from the microphone.
- **Negative-Tactile** – interventions where the assistant physically intervenes by moving the participants hand away from the microphone.

The analysis of the session using the authors intrusive interventions coding system within the Anvil Video Analysis Tool[5] illuminate the depth of the unintentional but nevertheless intrusive interventions to the extent that;-

- The interventions affected Freddie's interaction with the visual feedback.
- The interventions directly curtailed Freddie's interaction with the microphone.

It must be stressed that the analysis shows these interventions occurred *after* the subject was already engaged in an activity and not to encourage engagement in an activity.

Figure 3. *The support worker moving the participant's hand away from the microphone during vocal interaction with it.*

5. CONCLUSIONS

The findings corroborate with researchers who have found that there can be an excess of interventions or dominance in shaping events from caregivers in interactions with people with intellectual and physical impairments (e.g. Nind & Hewitt, 1994). There appears to be an inherent wish to 'jump in too soon' if a participant does not 'perform' to a pre-conceived idea of what they are supposed to do (Brooks and Petersson, 2007) also a unintentional cosseting of activity such as the 'aww bless' mindset (Williams, 2004). An assertion is made here that some of these interventions are a kind of projected positive outcome that the assistant may want to achieve or experience themselves rather than allow the participant to experience some independent activity or connection with the *aesthetic resonance* (Brooks et al, 2002) that may occur as a result of intense engagement with the environment.

The results of case study 2 would indicate a counter example of the findings of Petersson (2006) and Brooks and Petersson (2007). They posit that time to reflect on dialogues, whether verbal or non-verbal is necessary from facilitators acting within the interactive spaces. The author posits that interactions within such multimedia environments should be grounded in responses rather than initiations which has implications for training potential facilitators and those other people present at such sessions. It would be appropriate to add that further research in designing improved systems and methodologies is necessary to develop this area of research. The continued employment of expert gesture analysis tools such as the Anvil Analysis Tool in tandem with adaptations to tools based on the *Component Process Model of Emotion* (Scherer, 1993) and techniques such as *Recursive Reflection* (Brooks and Petersson, 2005) should ensure further inroads into the theory, understanding and knowledge base of multimedia multisensory environments.

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Customization of gaming technology and prototyping of rehabilitation applications

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ABSTRACT

The field of rehabilitation has recently seen various experimentations with games using interfaces that require physical activity. In order to establish the basis for developments and experimentations with those interactive systems, we propose a rapid prototyping approach using various commercial devices and open source software. To demonstrate this idea, we first show how a simple free game can be adapted to specific needs − for training or use by disabled people − by using different sensors and control modes. Similarly, we show that an open on-line virtual world such as Second Life, although not perfect, offers sufficient conditions for quickly building custom content and testing with usual interactive devices. When presented to these prototyping possibilities, people from the target group (health care professionals, patients, handicapped, families) are able to relate to their needs and to elaborate on the use of such systems. In other words, the availability of a simple prototyping platform with free games and new interfaces already opens the discussion on the design of original rehabilitation applications.

1. INTRODUCTION

An increasing trend in gaming is the use of interfaces that require physical activity for an optimal user experience (e.g. the Sony EyeToy[1] or the Nintendo Wii[2]). These and other similar sensor-based interfaces offer new opportunities for players to interact with a game so as to become more engaged. Previously, such interaction were mostly restricted within the domains of virtual reality research (e.g. Vivid's Mandala system; Vincent 1993) or professional arcade games (e.g. light guns, Meyer et al. (1979), Bartels et al. (2004)). Such gesture interaction technologies are not new; however, their recent availability as interface means within affordable mass-market gaming products can be seen as evidence of a broadening usage beyond solely entertainment.

Marginal application areas for games, such as within the field of rehabilitation, challenge the use of such interactive interfaces from various perspectives. To mention only few possibilities, Rand et al. (2004) reported how the Sony EyeToy can replace Vivid GX for stroke rehabilitation, or, as mentioned by Ijsselsteijn et al. (2007), the Nintendo Wii Bowling can keep elderly people fit in retirement homes. Such uses of console games 'as-is' in a different application context are interesting as a proof of concept, but they also usually outline the limitations of the commercial products and their inadequacy to the specific needs. Adaptability to each specific user and evaluation of use are two examples of what we consider to be improved.

We have encountered the limitations of console or PC video games for rehabilitation in many occasions. For instance, we were recently in contact with a family wishing to provide their severely motor handicapped son with the possibility to play computer games. What they found commercially available was the JoyBox[3] – a simple device acting as a joystick – with two large push buttons that could be positioned on each side of their son's head to steer left and right. When observing him play a motorcycle simulation game a mis-match was evident between the interface and his limited motor skills; in other words there was no way for him to drive the vehicle efficiently. What resulted was a poor gaming experience and frustration. This experience strengthened our belief that it is possible to design and develop an improved interactive systems for such a person. We targeted various sensors to be tested, potentially incorporated into a dedicated program that could be made so as to offer the possibility to tune the interface parameter controls and to choose an adapted content. This kind of (ideal) mix 'n' match solution does not exist at this time, as normally, to create such a product requires industry intervention due to the engineering and support affordable only to a commercial company. This leads us back to the original problem: commercially profitable solutions are made for the masses, and do not fit special needs...

This experience echoes a former experiment by Brooks and Petersson (2005) who created a video game platform room that was accessed by children in a day-care ward at a number of international hospitals. Among other conclusions, the study demonstrated that the Eye-Toy game adaptation was limited such that both interface and content could have been improved to address the children's different abilities. When approached about a research project to address these needs in the field, the industrial partner stated their desire, as a commercial company, to not be associated with disabled children as they feared being seen as exploiting them. This example shows that, despite the reality of the needs and the potential markets of the increasing aged and disabled in society, another approach has to be found to progress in this area.

What we suggest is to shift the focus of the problem away from the product design and more towards a focused prototyping opportunity, where custom devices and software can be tested for a specific user. Providing people having a specific need for rehabilitation (patients or therapists) with the ability to test new technologies is the primary requirement for the design and emergence of innovative tools. More specifically, application prototypes are very efficient communication supports in the collaboration between experts (patients/families and/or therapists) and technological experts (developers and/or researchers). This is precisely what the current gaming interfaces and the open source software community can provide; an affordable access to an increasingly large range of devices, and the possibility to freely use and customize software with various levels of technical skills required.

In order to demonstrate this, we built a number of different interactive systems by interfacing free open source games — for example Planet Penguin Racer[4] or Neverball[5] — with various interaction devices — web-cam, Soundbeam[6], Wii controllers, compass sensors, etc. We have originally been using these systems as demonstrations for medical or pedagogical professionals to show how the technology can be adapted. What we experienced is that, from their point of view, these systems are perceived as potential applications and this despite the technological simplicity and the use of pre-existing software.

This paper shows how prototyping of rehabilitation systems can be done in practice, first by comparing different devices and control modes for one game, and second by quickly prototyping a game adapted to one device and a specific control mode. We will then present the feedback we have had when using this approach and discuss the problems still to be resolved.

2. HARDWARE PROTOTYPING

The principle of our approach is to take existing games and to swap the usual keyboard and mouse interaction paradigm with more physically involving interfaces. This is done by modifying a game whose source code is available, and by integrating the code for reading the input from other devices.

2.1 Testing Platform

In this experiment, we had the focus to exemplify our research by using the game Planet Penguin Racer (PPRacer). This is an open source project sufficiently established and advanced to offer good quality graphics, sound and game-play. This is a racing game where the user controls a penguin descending a snow-covered mountain route. The challenge is for the player to maximize his or her score by targeting herrings that are strategically placed along the way, while missing trees and arriving at the end of the route in the shortest time possible. The thrill of playing comes from the feeling of speed, the risk of hitting obstacles, and the possibility to jump to save time. The fun of the game also simply comes from the empowered direct control of an artefact in a virtual environment.

The three motion sensing input devices we tested for controlling the penguin were: a camera, a SoundBeam ultrasonic distance sensor, and three-axis accelerometers. Here is how each interface works and which steering paradigms we found possible. They will be compared later on in the discussion.

2.2 Camera Interface

In the case of the camera device, motion is detected by frame subtraction. The steering direction and intensity are computed according to the amount of movement detected in the left and right quadrants of the camera field of view. The central area is neutral. In addition, acceleration and braking can be computed similarly from activity detected at the top and bottom of the image respectively. Processing of the camera image is via the Open Computer Vision Library[7].

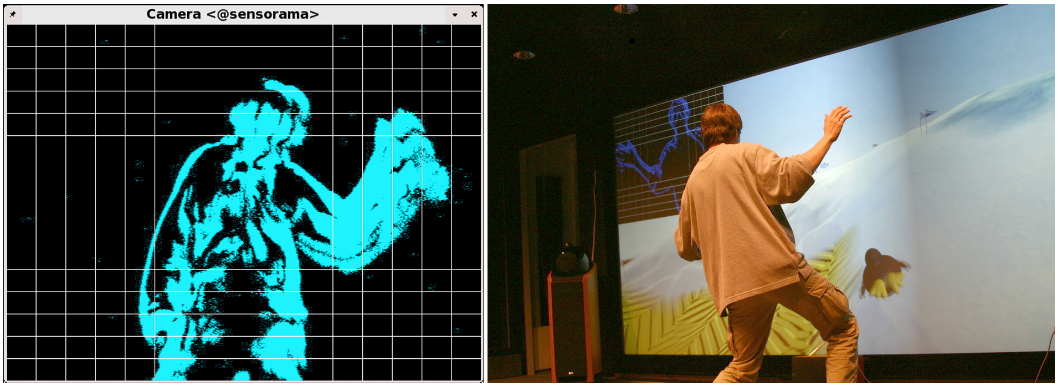

Figure 1: *The camera motion tracking grid — a player steering the penguin with body movements.*

The user is positioned in front of the camera which, in our case, was positioned under the screen facing the player so that movement on either side is used to steer the penguin. A minimal level of light on the player is required for the camera to detect motion. Players can wave one or both hand(s), lean on one side, make a step in either direction, or otherwise control via selected gesture. A repositioning of the camera can enable a level of head control. Figure 1 shows the action and the motion detection grid.

Figure 2. *The SoundBeam device – a player steering the penguin with head movements.*

2.3 Ultrasonic sensor interface

The Soundbeam is a commonly used device at special schools and institutes. It is used mostly for making music by gesture (“piano” keyboard in the air). We adapt it in our work into a game interface. The sensor device measures the distance between the ultrasonic emitter-receiver and an obstacle reflecting the narrow beam. In this case, the distance measured by the device is only used to steer left and right.

Considering a calibrated measurement range (e.g. [0:50] cm), the centre corresponds to the neutral position (e.g. 25cm), a shorter distance steers in one way (e.g. [0:25] cm with device on the left steers to the left) and a longer distance steers in the other way (e.g. [25:50]). The best way to use this interface is to sit in a chair and to turn and lean the head to the side (with the device pointing at the head as in figure 2). Full body movements are not recommended as the user may move out of the rather narrow beam and lose control.

2.4 Acceleration sensors interface

For the third interaction paradigm of our study we focus on accelerometer sensors, similar to those used in Nintendo Wii controllers. They are affordable and easily interfaced with electronic controllers so as to communicate with a PC via USB or other means. Using these sensors, we measure the orientation of the accelerometers relative to the vertical direction (gravity). As shown in figure 3 (left), they can be placed and fastened on the wrists of the player or positioned on a cap to capture head movements.

To control the game, we use the two resulting deflection angles from the wrist sensors to detect the orientation of the arms (figure 3, right). Mapping of the sensor data enables steering gestures such as: the neutral posture (penguin glides straight ahead) is with the forearms almost horizontal, lowering a single arm means touching the ground and therefore initiates braking on the side of ‘contact’ (similar to rowing a boat). Lowering both arms acts as a brake, and raising both arms accelerates the penguin’s descent. A brief user calibration also allows using a comfortable posture for the neutral position.

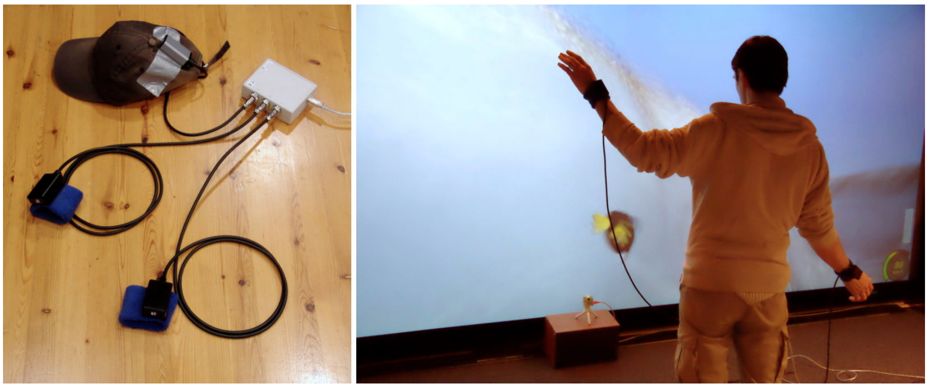

Figure 3. *The three accelerometers – a player steering the penguin with arms movements.*

3. SOFTWARE PROTOTYPING

While developing interactive systems for use in rehabilitation, we have encountered several major issues:

- Each and every case is different. Every user has different needs and different capabilities and the software and content need to be extensively customized every time.
- The customization has to be done quickly, ideally directly on the spot, in response to the immediate actions of the user or therapeutic needs. This is important especially when trying to find out what kind of activity is appealing to the user, because it is often difficult for these people to travel and/or endure multiple trial sessions.
- Ideally, the content customization should be doable by a person without specialized skills, perhaps after a short training. Most software used in this context is either not customizable at all, or requires specialized skills and software, for example game engines re-purposed for rehabilitation applications – Robillard et al (2003), Rizzo et al (2006) – to adapt the functionality.
- Communication between the users (both therapists and their patients) and the engineers providing support is difficult – it is often easier to show how the idea should work than to describe it to the other side, but that requires that the content is user-modifiable.

All these issues give raise to the need for a perhaps incomplete, but simple and readily available prototyping and testing platform. In order to satisfy this need and to demonstrate the possibilities available in the off-the-shelf free software, we are proposing a rapid prototyping approach using the Second Life® virtual world developed and maintained by Linden Lab[8] since 1999.

3.1 Testing platform

Second Life virtual environment is an online persistent world, with the users connecting to it using specialized software (client). This software is a free download, with the source code available as well. The key difference from other similar applications that enables us to use Second Life as a prototyping and testing platform is the fact that the entire virtual world is user-built with simple tools provided directly inside of the user’s client. Non-interactive content can be built literally by clicking and dragging the mouse, interactive content can be obtained using the built-in LSL scripting language. Furthermore, a lot of pre-made material can be obtained easily either for free or for modest payment.

On the other hand, Second Life has also few significant technical shortcomings, limiting its usefulness mostly to prototyping and situations where a tightly controlled environment is not absolutely necessary and occasional technical glitches are tolerable. Most of the problems stem from the fact that the system is a massively multi-user application, with tens of thousands of people being simultaneously online at any given moment. The other users can teleport from place to place, engage a user’s avatar in conversation or even attack it at any given moment, potentially disturbing the session. The system also suffers from chronic performance and scalability problems, especially during peak usage times, resulting in frequent outages.

Finally, there are also therapeutic issues with virtual worlds, such as users trained to perform certain tasks in the virtual environment may not necessarily be able to transfer the acquired skills to the real world or users performing significantly differently in the virtual environment due to the effect of anonymity/"mask" provided by the avatar. These issues are not specific to Second Life, though – similar problems face the users of any online multiplayer games when repurposed for the rehabilitation/therapy needs. A good analysis of these issues can be found in Gaggioli et al (2007). Any attempt to use virtual environments for such purposes will have to take these into account.

Figure 4. *Examples of possible activities in Second Life – navigation by flying, riding a jetski, car racing.*

The two following sections present two examples how content can be easily adapted and prototyped within Second Life. These examples were developed with the boy from the introduction in mind – severe motor handicap, spastic, confined to the wheelchair and using a Joybox to interact with a computer. The objective was not to provide therapy as such, but to enable a form of entertainment and an environment to exercise both his cognitive and motor skills. The setup has still to be tested with the child.

3.2 Avatar Navigation and Vehicle Driving

The first simple scenario is an attempt to get the user familiar with the controls and basic navigation in the environment. One popular way how to explore the virtual world is to fly. In this case, we have used an island with a lot of interesting things for a child to explore and have set up the controls in a way that allow the steering of the flying avatar (figure 4 left). The main issue with this task is that full control of the flying avatar requires at least 3 degrees of freedom (turn left/right, move forward/backward, climb/descend), necessitating 6 buttons or a regular gamepad to use. As such, it is not a very practical application.

In order to constrain the number of degrees of freedom required, we have got inspired by a racing game that comes with the Joybox device. The boy had major problems controlling that game, firstly because it was too difficult and secondly because the controls didn't map too well to the binary on/off nature of the switches of the Joybox. Second Life allows building all kinds of vehicles and driving them is a popular activity. We have adapted some of them to the limited controls provided by the Joybox device. In order to keep the things simple, we have constrained the controls and used only two switches for lateral steering, without brakes and throttle, letting the vehicle move forward at a constant speed on its own. The boy is used to two buttons, either as two large push buttons on the table or two head switches attached to his wheelchair, so this control arrangement shouldn't pose a large problem for him. The arrangement is shown in figure 4 centre and right, with the avatar riding a jetski and racing a car.

3.3 Content Customization

The scenario described in the previous section allows wide options for adaptation, depending on the needs, skill and interest of the user. For example, the driving can be made easier or more difficult by swapping the vehicle for another one, with different characteristics (such as a scooter for a sports car). Obstacles, such as traffic cones or boxes can be easily added or removed or the track redesigned. Competitive racing with family, friends or other users in the same virtual environment is possible without any extra effort. All this can be done by a non-technical user after a short demonstration – parents, helpers, therapists.

Figure 5 shows the process of constructing a simple obstacle course for a motorbike using the built-in tools. In the left image the user is shown constructing a simple traffic cone out of two pieces – a flat and square stand and a conical top. These traffic cones are then placed in the environment for the user to drive through (right sub-figure). The built-in tools are quite primitive, but a lot can be built in a short time with little effort – a valuable feature for building quick prototypes for testing various approaches or to adapt the environment on the fly, depending on the immediate needs.

Figure 5. *Example of content customization – building a simple obstacle course.*

4. DISCUSSION

We have been intensively presenting our games to a broad public, both in our laboratory facilities and at some exhibition places. We tried to experiment with handicapped persons as often as we could to get a better knowledge on the adaptability of our approach, and to learn what should be the next development step. Here is a synthesis of observations and feedback we obtained.

4.1 Tests and Limitations with our Prototypes

The learning curve to play the penguin game is negligible and this was evident by people's responses who often upon achieving an easy level would ask to play a level more in line with their skill level. Compared to the camera interface, the accelerometer based system offers an increased intuitiveness in control due to a decreased latency in the control and the ability to break (and thus make sharper turns). In addition, lighting is not a prerequisite for this interface. On the other side, the camera does not require to wear anything and avoids the cables which can be somewhat encumbering. A wireless version of the accelerometer device or the use of Wii controllers (same technology, but to be held in the hand instead of placed on the wrist) could offer a good compromise.

In a further experiment, we tested the ultrasonic Soundbeam device with a profoundly disabled young adult controlling via head movement. She played the game in front of a 5 meter wide by 2 meter high back projection screen. Although she was unable to speak, her two helpers interpreted that her communication was of being very excited and happy at having fun. She continued playing until exhausted. The device is hard to setup precisely though, as it only detects movements along an invisible line in space (the player may accidentally get out of the line). Comparatively, the camera is easier to adjust according to each person's disposition (e.g. wheelchair) and preference (whole body movements, limb, or head). The visual feedback from the camera field-of-view is essential for placing the person optimally in the neutral zone before starting.

Development wise, the examples presented for hardware prototyping did require little but expert programming. This is equivalent to what we ask to our Bachelor students in C / C++ programming projects. Regarding electronics, only our home made solution for the accelerometers required a bit of engineering, but those can be replaced with Wii controllers without problem. The software prototyping presented is, as stated, approachable to any computer users, but more can be done with computer science experts.

4.2 Feedback from Presentations at Scandinavian Rehab Messe 2007 and 2008

To get an initial feedback on the approach from rehabilitation professionals, we presented the concept at the REHAB Scandinavia in 2007 and 2008 — an international Messe event presenting products from the Scandinavian health care and rehabilitation market that is held annually in Denmark. Our stand was set up for live demonstrations of games, including our adapted PPRacer with camera interface.

Attendees at our stand ranged across the spectrum from potential users including therapists and associated medical experts, disabled people and their family/friends, to those in associated industries, i.e. commercial distributors, related educations and national/international representatives of organizations. The community of potential end users that tested the system, i.e. the people with impairments, physiotherapists and occupational therapists, were especially interested in the adaptability of the system. The commercial entities observed the system in use rather than tried it themselves, but their response was also positive and word of mouth was such that, during the last two days of the three day Messe, people were arriving to try the system telling us that others had told them of it. We also noticed people returning to try it so as to beat a previous score. These 'players' also exhibited a sense of self-esteem as they performed for the public.

Unanimous positive feedback was received. The line of people waiting to try the system was in itself an indication at the potentials of the concept. Many people after testing or observing the interactive system asked us if they could purchase it, however, as it is a research prototype this was not possible.

Figure 6. *REHAB Scandinavia 2007 and 2008; steering the penguin when exercising on a fitness ball.*

It was also observed that the therapists would often test the game and then communicate to their colleagues who were observing of how it would suit to be used for a certain person in their care. This selective referencing to people with impairments at their institute was interesting as they visualised that person in the game scenario and placed themselves into that role, in line with the precept out of the Chicago school of sociology and specifically the work of Robert Park.

Reflecting on some of these comments, we borrowed a large exercise ball commonly used in physiotherapy to experiment with the camera control of the penguin game. To control the Penguin by sitting on the ball required lateral and frontal movements of the lower back, waist and hip region, whilst simultaneously keeping balance with the feet on the ground. The size of the ball fitted the size of the large screen feedback well as the player could range from maximum left-to-right through a movement of the feet (from heel-to-toe or vice versa) that corresponded to the flexion of the seated area. The upper torso could be static or more active. Generally speaking each person exhibited different characteristics of 'naturally interacting' – with the ball (i.e. that which mediated control of the game) – and the penguin (i.e. the controlled artefact which in turn through the mapping strategies was mediating the responsive movement of the player).

This natural, or intuitive interaction, is achievable (and arguably optimal) when the player is unencumbered, i.e. no attachments or held device required so as to be able to move freely. This autonomous efferent response (feed-forward) to afferent stimulus (feedback) was quickly identified in most players, even in such a short demonstration framework. Flow state, as defined by Csíkszentmihályi (1990), and ludic engagement were also suggested by observers. Many of the physiotherapists excitedly speculated to us of benefits such as eye-to-hand coordination, concentration, balance training, proprioception training, general lower-upper limb coordination, and more.

5. CONCLUSION

The examples presented in this paper typify our approach towards a targeting of optimal player experience through adapting interface or content to match needs, preferences and abilities. It also illustrates how we have attempted to approach one of the current problems that we see between the commercial gaming solutions and the specific needs for rehabilitation training or people with disability.

We can conclude that such an approach of taking existing software and hardware technologies as a foundation for a cross-disciplinary user-centred design of dedicated applications can provide professionals and educators with new opportunities in rehabilitation. Software and hardware prototyping can be greatly reduced by adapting off-the-shelf open source solutions to a therapeutic need. Our approach has exhibited opportunities that can evolve if an effort is taken to open spaces for dialogue between the various associated disciplines. Such opportunities and methods of use have to be disseminated and made available to society.

The confrontation of various interaction devices and paradigms for gaming situation should also develop therapists' awareness to the possibilities of new technologies, and hopefully raise new ideas of scenarios for psychotherapeutic training, eventually leading to a fully custom solution once the needs and requirements are clear.

The creation of libraries of adaptable input devices alongside adaptable content would be optimal to suit preferences, desires, as well as the physiological or psychological profiles. If realised, such an open platform could become an evolving vehicle for openly sharing interdisciplinary and multidisciplinary knowledge alongside user/expert experiences with easy (authorised) access for use. Such a platform could be centralised with on-line real-time interaction as a distinct possibility.

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Session VI

Motor Rehabilitation

Chair: Evelyne Klinger

Virtual reality system for upper extremity rehabilitation of chronic stroke patients living in the community

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ABSTRACT

For stroke patients with residual motor impairment, access to sufficient rehabilitation after discharge is often difficult to achieve due to cost, distance and availability of rehabilitative services. Virtual Reality (VR) rehabilitation is a promising method for maximizing the intensity and convenience of task specific rehabilitation training. However, many of the systems that have been developed are expensive, heavy and require frequent technical support. This feasibility study was the first phase in the evaluation of a commercially available game controller for leisure-based therapy at home. Eight people at least six months post stroke took part in a two group randomised control trial. Participants completed a range of measures of upper limb functioning before half spent three sessions a week playing computer games using the game controller while the other half spent the same amount of time in a progressive muscle relaxation program. The study is still underway so data are presented on the performance of the participants in the games group. Their results so far suggest that participants have the potential to improve their performance on the games available using this device.

1. INTRODUCTION

Stroke is the third most common cause of mortality and the leading cause of long-term disability worldwide (Mackay and Mensah, 2004). The literature suggests that 75% of survivors regain their ability to walk again, however a considerable proportion ranging from 55% to 75% fail to regain functional use of their impaired upper limb (Feys et al., 1998). Upper limb motor impairment limits the individual's functional autonomy and activities of daily living. In the UK the National Clinical Guidelines for Stroke recommend rehabilitation which focuses on "participation" and includes planned withdrawal of medical and rehabilitation services and substitution with leisure and social activities that encourage independence and reintegration to normal life (RCP, 2004). However, access to further rehabilitation is often difficult to achieve after hospital discharge, due to cost, distance and availability of rehabilitative services (Reinkensmeyer et al., 2002).

To address the need for augmented rehabilitation, several research groups have explored the use of emerging technologies. Within this context Virtual Reality (VR) rehabilitation has been heralded as one of the most promising methods for maximizing the intensity and convenience of task specific rehabilitation training (Dobkin, 2004). Indeed scientific evidence suggests that early intensive (Kwakkel et al., 2004) task specific (van Peppen et al., 2004) practice for a prolonged period of time (van der Lee et al., 2001) facilitates motor recovery. Additionally, various forms of augmented feedback are considered to be a potent variable affecting motor skill acquisition following stroke (Van Dijk et al., 2005).

Preliminary research in the area of VR stroke rehabilitation focused primarily on examining the feasibility of complex VR systems that provide the participants with different types of augmented feedback and different VR rehabilitation protocols for acute, sub-acute and chronic stroke patients (eg Merians et al., 2002). Although this work mainly involved small sample sizes it suggested promising trends, triggered the active exploration of telerehabilitation applications (eg Broeren et al., 2004) and finally lead to further studies involving bigger sample sizes (Holden et al., 2007) and small controlled clinical trials (eg Piron et al., 2006). This later work established the feasibility, health and safety of VR stroke rehabilitation systems and indicated that previously obtained positive outcomes were not attributed to spontaneous recovery (Holden et al., 2007). Neuroimaging studies also demonstrated that VR training can induce cortical reorganization following stroke (Takahashi et al., 2008).

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Given the fact that most of the above systems employ relatively sophisticated or expensive hardware and software, one question of paramount clinical importance is whether the benefits obtained from these systems can outweigh their cost or if similar results can be obtain with less sophisticated affordable systems. What now needs to be explored is the rehabilitation potential of commonly available VR platforms and games. Although commercially available platforms lack specificity in terms of software, hardware and performance metrics they often provide other equally important advantages such as mass acceptability, easily perceived feedback and most importantly affordability for unrestricted home use. In addition some of these platforms and games share similar characteristics to their higher cost predecessors. For example, they take an egocentric perspective combined with a virtual representation of the hand and this further enhances the potential to facilitate improvement through activation of relevant motor areas of the brain (August et al., 2006).

We set out to evaluate a highly acceptable, usable and accessible VR rehabilitation system for leisure-based therapy at home. Feedback from focus groups conducted with the local Stroke Research Consumer Group suggested that VR rehabilitation is very acceptable and clinically relevant to chronic stroke survivors and that a device to play appropriate computer games would motivate users to continue with the activities at the recommended frequency. Following a review of existing technology, we decided to use a commercially available game controller, the Novint Falcon (http://home.novint.com/products/novint_falcon.php). This has several advantages for home use including low cost, size and weight; 3 degrees of freedom to allow the development of motor schemata that underlie everyday tasks; safe force feedback for building strength, speed, endurance and precision of multijoint movements and easy calibration for non experienced users. The software available with the device includes a variety of VR mini-games that motivate users to perform sufficient repetition of tasks aligning with established neurorehabilitation principles such as task variability and contextual interference (Krakauer, 2006).

Before embarking on an evaluation of the intervention in patients' own homes, a hospital based feasibility study was required to determine the design; sample size; suitable outcome measures that assess improvements in functional ability; the procedure for the home based study and any changes to the prototype to enhance its usability in a home based setting. As this study is still in progress, results from the performance of the intervention group only are presented in this paper.

2. METHODS

2.1 Design

A small two group randomised control trial with 4 participants in each condition.

2.2 Recruitment of Participants

Potential participants were recruited from two stroke clubs. Invitation leaflets were handed to members who were aged between 18 and 85 years, had experienced their stroke more than 6 months previously, were still experiencing problems with their upper limb for which they were receiving no formal arm therapy and who lived in the community. Volunteers first had to complete a screening questionnaire which included a set of questions about their arm function, general mobility and health and safety designed to exclude those whose current condition would prevent them from using the system for the required period of time. If their answers indicated that they were suitable for the study, one of the research team (AC) visited them at home to further assess their suitability using a set of standardized outcome measures of cognitive, perceptual and motor function corresponding to the VR tasks that the participants needed to perform. These measures were the arm section of the Motricity Index (MI) (Demeurisse et al., 1980); Modified Ashworth Scale (MAS) (Bohannon and Smith, 1987); Mini-Mental State Examination (MMSE) (Hodgkinson, 1972): Star Cancellation Test (STAR) (Wilson et al., 1987) and the Sheffield Screening Test for Acquired Language Disorders (STALD) (Syder et al., 1993). The MI and MAS were also used as secondary outcome measures. Potential participants were also excluded if they also suffered from other serious conditions.

8 people were recruited to the study who met the above criteria. There were 4 men and 4 women aged between 36 and 74 years. On recruitment, participants were randomly assigned to either the VR Leisure or VR Relaxation group. Table 1 shows the characteristics of the six participants who have already started the study.

Table 1. *Baseline characteristics of the participants.*

	VR leisure	VR relaxation
Sex (Male/ Female)	2M/2F	1M/1F
Age (Mean/Range)	62.75/36 - 74	57/56 - 58
Months since stroke (Mean/Range)	58.25/12 - 116	121/36 - 206
Hand dominance (R/L)	3R/1L	2R
Side of weakness	3R/1L	2R
STAR (Mean/Range)	52.5/51 - 54	54/54 - 54
STALD (Mean/Range)	16.5/8 - 20	18/16 - 20
MMSE (Mean/Range)	27.25/22 - 30	26.5/25 - 28

2.3 Measures

A variety of outcome measures corresponding to different aspects of upper extremity activity were included in this feasibility study to ascertain suitable outcome measures for the home based study; to ensure that the participant's upper limb status did not prevent them from effectively using the system and to assist with power calculations for the home based study. All measures have been demonstrated to be valid, reliable and relevant to the upper extremity while also being convenient to administer as the whole battery can be performed in about 30 to 35 minutes.

2.3.1 Primary Clinical Outcome Measure. The Action Research Arm Test (ARART) (Lyle, 1981). This is a staff-scored, patient-completed 19-item test divided into 4 domains: grasping, gripping, pinching and gross movement. Each item is graded on a 4-point ordinal scale for a total possible score of 57 indicating normal arm functioning. The test is hierarchical in that if the patient is able to perform the most difficult skill in each category, they are assumed to be able to perform the other items within the category.

2.3.2 Secondary Clinical Outcome Measures.

The 10-Hole Peg Test (PEGS) (Annet, 1970) was used to assess manual dexterity. This is a staff-scored, patient-completed measure of manual dexterity consisting of two parallel rows of ten holes and ten pegs. The participant has to move the pegs one by one from the further to the nearer row, when the board is placed horizontally across their midline. The time taken is recorded from touching the first peg to releasing the last, to an accuracy of 1/10 seconds. There are 10 trials each trial alternating between the right and the left hand. The mean completion time for the five trials with the left hand is subtracted from that for the right hand so the larger the resulting figure, the larger the difference between the affected and unaffected side.

The Motricity Index (MI) (Demeurisse et al., 1980) was used for assessing motor impairment. The MI is a staff-completed index measuring general motor impairment on three basic upper limb subtests (pinch grip, elbow flexion and shoulder abduction). The maximum score that can obtained is 100 indicating normal functioning.

The Modified Ashworth Scale (MAS) (Bohannon and Smith, 1987) is a measure of spasticity. It is a staff-completed manual test that staff use to grade the resistance encountered during the passive stretching of different spastic muscle groups. It involves applying rapid manual movement of the limb through the range of motion to passively stretch specific muscle groups. Each joint is scored between zero and five with zero indicating no increase in muscle tone.

The Nottingham Extended Activities of Daily Living (NEADL) (Nouri and Lincoln, 1987) was used to asses the participant's ability to carry out activities of daily living. The NEADL is a patient or carer-completed measure of Instrumental ADL ability comprising 22 items grouped into 4 categories: mobility; kitchen tasks; domestic tasks; leisure activities. The maximum score is 60 indicating full independence of daily living activities.

2.3.2 User Experience Outcome Measure. The Short Feedback Questionnaire (SFQ) (Kizony et al., 2006) and the Borg Scale of Perceived Exertion (Borg, 1990) were used to assess the participant's experience of using the system and physical effort respectively.

2.4 Virtual Environments

2.4.1 VR Leisure Group. From the games that were provided with the Novint Falcon, five were chosen that would motivate the participants to use their arm in order to perform sufficient repetition of upper limb movements/ tasks (i.e. pull, push, reach, grasp) to help them produce improvements in their upper limb motor control and function.

The five games differed in terms of the motor activity that was required to play them so that a combination of the games provides the opportunity a) to focus on different aims based on the users abilities, needs and preferences; b) progressively increase difficulty and complexity by moving to more complex games and c) provide a combination of games (i.e. task variability). Details of the games and skills required are summarised in Table 2.

Table 2. *Summary of the details of the games available for the VR leisure group.*

Game	Description	St	Sp	E	P	C	RT
Penguin Push	Push forward to shove the penguin along the ice and slide it onto the target at the end of the ice				✓		
Hook & Weight Fishing	Swing the fish over to the bucket to collect the fish	✓	✓		✓	✓	✓
Cucaracha	Hit the approaching cockroaches with a hammer before they reach any of the food or beverages on the table		✓		✓		✓
3-Point Shootout	Grab a ball and shoot it from five different locations	✓	✓	✓	✓	✓	
Top Pin Bowling	Grab a bowling ball, throw the ball and knock over as many pins as possible	✓		✓	✓	✓	
Duck Launch	Grab the nearest duck, strap it into a giant slingshot, and fling it into one of the ponds	✓		✓	✓	✓	

St = Strength; Sp = Speed; E = Endurance; P = Precision; C = Coordination; RT = Reaction time

2.4.2 VR Relaxation Group. This involved listening to a recording of an instructor's voice describing a progressive muscle relaxation program. The program encouraged participants to imagine themselves in a relaxing environment similar to the virtual reality environment (VRE) presented on the monitor and to actively perform a contraction-relaxation program involving the same upper limb muscles as the experimental condition, however in the absence of functional upper limb movement. This condition (i.e. attention control) was carefully chosen in order to keep contact time consistent across participants as opposed to providing conventional therapy or providing a no treatment condition and was based on studies which suggest that similar control conditions keep participants interested, compliant, and blinded (Page et al., 2007).

2.5 Procedure

The intervention took place in the research laboratory. Participants had sessions scheduled for three times a week for four weeks which lasted 30-45 minutes but could be terminated earlier if they wished. When they attended for their first session they completed the ARAT and ten hole peg test before starting either the VR leisure or relaxation condition. For both conditions they sat in an ergonomic chair facing a 21″ widescreen computer monitor computer with one of the researchers (AC) sitting alongside them to give assistance and

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encouragement if required. The participants in the VR relaxation group wore a pair of wireless headphones to isolate them from the environment to allow them to focus on the instructions without external influences.

Participants in the VR leisure group started on the game that, in discussion with the researcher (AC) seemed to be the most appropriate to their current level of arm function. They then spent several sessions playing this game before moving on to play a second game and then a third. The games were quite short so that in each session the participant could attempt the game several times. Each session was recorded on videotape, with the camera positioned to view both the participant and the researcher sitting next to them. The videotapes were analysed using a method established in an earlier study (Standen et al, 2002) which yielded measures of help given by the researcher. This was described as physical (giving assistance) or verbal (giving information). The researcher also recorded the scores obtained for each attempt at each game and also the number of errors. A diary was kept to record any other information that might be useful but that would not be picked up by video analysis.

Video collected data were expressed as a percentage of session duration; scores and errors were averaged for each session. The purpose of collecting these performance data was to confirm that the games were set at a level suitable to the abilities of the participants and that with continued practice they had the potential to show some improvement.

3. RESULTS

3.1 Outcome Measures

As the study has not been completed, currently available results for six participants are presented. Baseline scores on the outcome measures are shown in Table 3.

3.2 Performance Measures

Figures 1 and 2 show the mean scores and errors over the sessions for which data are available for two participants on two of the games, Penguin Push and Top Pin Bowling. For all participants there was an increase in score obtained from the first to the last session (see Tables 4 and 5). However, these increases were accompanied by a decrease in errors for only three of the four participants: participant 5 playing Penguin Push had a higher mean number of errors in session six than they did in their first session. This suggests that whatever strategy they adopted to increase their scores was at the expense of accuracy.

Table 3. *Mean and range for each group at baseline on the outcome measures.*

	VR leisure	**VR relaxation**
Action research arm test	43.25/2 - 57	23/1 - 44
10 hole peg test	7.21/0.46 – 12.03	17.13/11.84 – 22.43
Motricity index right hand	74.5/40 - 100	62/40 - 84
Motricity index left hand	85/40 - 100	100/100 - 100
Nottingham extended activities of daily living	47.5/33 - 57	56/54 - 58

Table 4. *Comparison of scores and errors from first to sixth session for Penguin Push.*

	First session		Sixth session	
	scores	errors	scores	errors
Participant 4	1.40	0.73	3.00	0.42
Participant 5	0.78	0.44	1.97	1.02

Table 5. *Comparison of scores and errors from first to sixth session for Top Pin Bowling.*

	First session		Sixth session	
	scores	errors	scores	errors
Participant 1	1.77	0.87	3.06	0.89
Participant 2	3.39	0.36	4.79	0.05

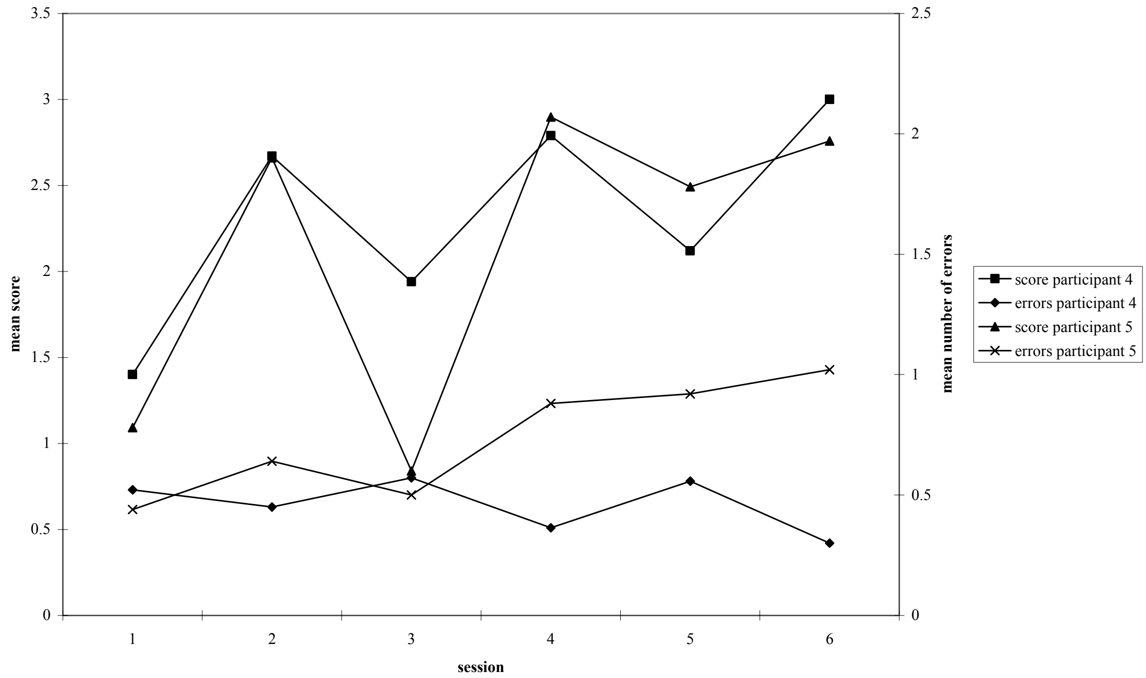

Figure 1. *Mean scores and mean number of errors by session for one game: Penguin Push.*

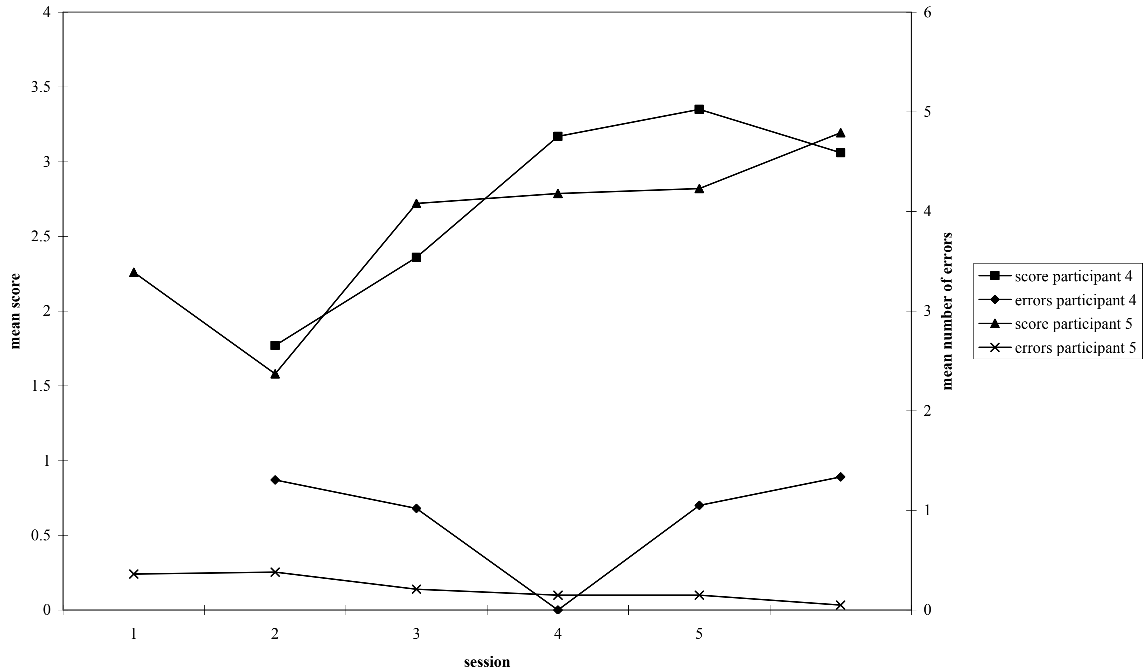

Figure 2. *Mean scores and mean number of errors by session for one game: Top pin bowling.*

4. DISCUSSION

As the study is still in progress it is not possible to compare changes from baseline in any of the outcome measures. However, an examination of the performance on the games suggests that some improvement is taking place even after only six of the total 12 sessions have been completed. The amount of help participants receive from the researcher has also been recorded to determine how much of the improvement may be due to external help. The tapes have not yet been analysed but informal observations indicate that after the first session, help diminished to almost zero indicating that the games are easy to learn and would thus be suitable for a home base intervention where the researcher was not continually present. Performance measures were collected to indicate whether the games were set at a level suitable to the abilities of the participants and that with continued practice they had the potential to show some improvement. It is possible that the improvement shown so far is purely down to increasing familiarity with the games but continued improvement over the remaining scheduled sessions would suggest that there was also an improvement in motor ability which would hopefully be indicated in the final administration of the outcome measures.

This is a small sample and the generous inclusion criteria ensured a wide variation in ability. However, useful findings for the planning of the home based study have already emerged. First of all, it is important to have a variety of games that would ensure that the activity matches participants' ability, needs and preferences and sustains their motivation for improving manual ability. Games that might require fine manual dexterity for example pressing the fire button, can be frustrating and demotivating for those pinch and grip capability is low. Secondly, in spite of having to make the journey to the hospital three times a week, no participants have dropped out of the study. Although other pressures will exist in a home based study that will affect compliance, playing the games or taking part in the relaxation condition appear to be sufficiently motivating to maintain continued participation. Finally it was interesting to hear from one of the participants in the VR leisure group that between sessions he had been encouraged to attempt more manual activities at home for example opening screw top jars. This suggests that the future study should try to incorporate an extra measure of daily activity outside of the gaming sessions.

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Virtual reality in the rehabilitation of the upper limb after hemiplegic stroke: a randomised pilot study

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ABSTRACT

The aim of this study was to assess the feasibility of an RCT to investigate VR mediated therapy in comparison to standard physiotherapy alone in the motor rehabilitation of the upper limb following stroke, and to provide data to inform a power analysis to determine numbers for a future trial. A single blinded randomised controlled trial was conducted. Participants were recruited from two hospital stroke units and members of local Northern Ireland Chest, Heart and Stroke Association clubs. The Upper Limb Motricity Index, Action Research Arm Test were completed at baseline, post-intervention and 6 weeks follow-up. 18 participants were randomised to either a VR mediated upper limb therapy group or a standard therapy group. No significant between group differences were noted. Both groups reported some small changes to their upper limb activity levels. Both interventions seemed to have been acceptable to participants. This study demonstrated the feasibility of a randomised controlled trial of virtual reality mediated therapy for the upper limb compared to standard therapy. Forty-eight participants (24 per group) would be needed to complete an adequately powered study.

1. INTRODUCTION

It has been suggested that underutilisation of the affected limb can occur after stroke (Taub et al, 1993) and people tend to compensate with the intact limb rather than attempting to use the more affected limb (DeLuca et al, 2003). Virtual reality (VR) may hold some solutions to these problems. It has been shown to be an interactive and enjoyable medium that, with sufficient use, may improve upper limb motor function in adults with stroke (Holden et al, 2007). VR technology can be used to produce an environment in which intensity of practice and feedback on performance can be manipulated to provide tailored motor training (Merians et al, 2006) (Reid, 2002). However, reviews in this field have indicated that although very promising there are still problems relating to sample size and the variety of methodologies used (Crosbie et al, 2007). More recent studies continue to report the variety of set-up and design of the VR technology. Examples of such are a novel upper limb system consisting of three-dimensional tracker, custom forearm support, workstation and library of Java 3D exercises (Kuttuva et al, 2006) and a haptic master-slave set-up (Houtsma et al, 2006).

Two recent trials have been reported (Jang et al, 2005; Fischer et al, 2007) comparing VR mediated therapy for the upper limb to no intervention and to alternative digital applications. In the trial reported by Jang et al (2005) significant improvements were found in the Box and Block Test; the Fugl-Meyer Assessment and manual function test. This study also reported a novel demonstration of VR induced neuroplastic changes associated with motor recovery as indicated through the use of FMRI. Fischer et al (2007) also report significant changes on the Box and Block Test and the Fugl-Meyer Assessment, along with a significant change in Wolf Motor Function Test score. However, the authors indicated that overall gains were small. At the time of commencing this work no trials had been reported comparing VR therapy to standard therapy. There remain a limited number of trials which compare standard therapy to VR based therapy. However, in the last year one study (Piron et al, 2007) has been completed in which 25 subjects received reinforced feedback in a virtual environment for the upper limb, with 13 subjects in the control group receiving conventional rehabilitation, however no detail of the content of these sessions is given.

2. AIMS AND OBJECTIVES

The aim was to assess the feasibility of an RCT to investigate the effectiveness of VR based therapy compared to standard physiotherapy in the motor rehabilitation of the upper limb following stroke. Objectives were (i) to pilot the methodological procedures; (ii) to assess the effects of VR therapy on the upper limb impairment and activity levels of people with stroke; and (iii) to provide data to inform a power analysis to determine sample size for a future trial.

3. METHOD

A single blind randomised controlled trial was conducted. The outcome assessor was blind as to group allocation and the research therapist was blind to outcome scores. Participants were recruited from two stroke units and via local stroke support clubs, all in the Greater Belfast area. Individuals were considered for inclusion if they were up to 24 months following their first stroke; and if they were: medically stable; could follow a two-step command; and had a score of 25 or above on the upper limb Motricity Index (MI) (Demeurisse et al, 1980). All participants were formally screened for confusion; excluded with a mental score of less than 7/10 (Hodkinson, 1972); and neglect; excluded with a Star Cancellation Score of less than 48/52 (Wilson et al, 1987). Participants were also excluded if they had co-morbid conditions, for example, cardiac, respiratory or orthopaedic conditions, affecting their rehabilitation potential and severe arm pain of < 7/10, as assessed by a visual analogue scale. People who had been fitted with a cardiac pacemaker were excluded, as the electromagnetic motion tracker used within the VR system may interfere with such devices. Participants did not report any sensory deficits. These extensive exclusion criteria were employed in an effort to recruit as homogenous a sample as possible form this population. Participants were randomised to either a standard therapy (ST) or VR based therapy. Randomisation was stratified within each group according to age (old = 72 years or more; young = 71 years or less). The Queen's University Belfast and the Northern Ireland Office for Research Ethical Committees approved the study.

4. INTERVENTIONS

Our research group has built a system for use in stroke rehabilitation (Crosbie et al, 2005) which gives the user the ability to move around a world composed of simple and familiar objects, and to interact with these objects by touching, grasping and moving their upper limb. The user wears a head mounted display unit (HMD), a mono Cy-Visor DH-4400VP. A 5DT stretch Lycra data glove facilitates manual interaction in the virtual world. An Ascension Flock-of-Birds magnetic sensor system provides real-time 6-degrees of freedom (position and orientation) tracking of up to four points on the user's body. A virtual environment (VE) has been created with a series of reaching and grasping tasks. The user sees a stylized representation of their arm and hand in the VE. Three sensors are attached to the major upper limb joints (shoulder, elbow and wrist) and the fourth is attached to the HMD to facilitate the sense of immersion in the VE.

4.1 VR Training

The VR group underwent a three-week VR intervention period. This consisted of nine sessions over a 3-4 week period. Each session was approximately one hour in duration, and consisted of participant set up; physical practice using the VR based system to encourage the user to produce specific upper limb activities and functions. The research therapist operated the system from a PC based station in the same room as the user. A few users required some assistance to don and doff the apparatus (HMD and data glove) and the researcher applied the motion tracking sensors to the upper limb. Once the set-up had been applied the user was free to choose upper limb exercises from the range of pre-programmed task and game activities. These involved the arm and hand reaching to a target(s); wrist extension exercises and functional reach and retrieve tasks. An element of choice was open to the user in terms of number of targets; height and distance placement; and speed of task performance. A game activity 'whack the mouse' was also incorporated into the sessions. Auditory and visual mechanisms provided feedback on the users' performance. Gaming aspects included: visualisation of the number of 'hits' in a score box; the addition of levels of difficulty, with adaptations to the users' speed and accuracy of performance. High scores were entered onto a 'leader board'. An element of problem solving was introduced to the game in level 3, where the user had to contact the virtual mouse, with the hammer, whilst avoiding a virtual dog (See Figure 1a and 1b for a screen shot of the mouse game and components of the system).

Figure 1a. Sc*reen shot of mouse game.*

Figure 1b. *Components of the University of Ulster VR rehabilitation system.*

4.2 Standard Therapy Training

The standard therapy (ST) group received therapy, focusing on the upper limb, to control for any dose effects in terms of the amount of intervention between the two groups i.e. both groups received therapy for the same length of time. This was delivered by a physiotherapist and followed a programme of conventional rehabilitation techniques, which included muscle facilitation techniques, stretching exercises, strengthening activities (Winstein et al, 2004) and the inclusion of the more affected upper limb in functional tasks. The content of standard therapy was recorded for each session using a treatment checklist As the same therapist treated both VR and ST groups, a physiotherapist with expertise in neurological rehabilitation, and who was not involved in the delivery of the intervention, verified that the therapy offered to the ST group was in line with current practice. One session each for six participants was video recorded to facilitate this process.

5. OUTCOME MEASURES

Upper Limb Motricity Index (Demeurisse et al, 1980) and Action Research Arm Test (ARAT) (Lyle 1981) were completed at baseline, post-intervention and 6 weeks follow-up. The Upper Limb Motricity Index was used as a method of assessing the level of impairment and has been described earlier in this paper. This measure was chosen as it has been shown to be a valid measure of motor impairment after stroke (Collin and D Wade, 1990; Parker et al, 1986). Further advantages of this measure are that it is short, easily applied and does not require specialist training for its use. The MI grades motor activity and is based on the MRC Oxford Classification of muscle action, assessing whether there is a muscle contraction, if movement is present and if movement is possible against gravity or resistance. The upper limb section is scored out of a possible 100, with 0 indicating no muscle contraction palpable. A score of 0-25 out of 100 indicates very severe impairment; 26-50 is severe; 51-75 is moderate and 76-99 is mild impairment (Sanchez-Blanco et al, 1999).

The ARAT was constructed for assessing recovery of upper limb function following cortical brain injury. Motor actions, including arm movements and hand functions, are graded on a 4-point ordinal scale. The test is divided into four domains – grasp, grip, pinch and gross movement – and items are arranged in order of difficulty. Items within each subscale are ordered in such a way that if the person accomplishes the most difficult item, this predicts success with all less difficult items (Hsieh et al, 1998). This measure was chosen as it has been validated for use in people with stroke and has been shown to have high inter-rater and test-retest reliability (Platz et al, 2005). The ARAT provides meaningful information about functional recovery after stroke (Hsueh et al, 2002).

6. DATA ANALYSIS

All data were analysed using the Statistical Package for the Social Sciences (Windows 12) according to the intention to treat principle. Descriptive statistics compared baseline characteristics. Non-parametric tests were used due to the small sample size of this pilot study. The Friedman test was used to determine any differences between values measured across the three time points (baseline, post-intervention and follow-up). The Mann-Whitney U Test was used to identify whether the difference lay within or between groups. The Mann-Whitney U tests the assumptions about differences between median values in two groups. Missing data points were dealt with by the simple mean imputation method. The mean score of the group replaced missing values at a particular time point.

7. RESULTS

Seventy-seven potential participants were contacted. See Figure 2 for flowchart of study according to CONSORT statement (Moher et al, 2001). Three people were deceased at time of contact. 56 people were excluded for the following main reasons: unwillingness to participate (n = 23) non-response (n = 4) and ineligibility according to the inclusion criteria (n = 29). 15 people (20%) were unwilling to participate. Three people were attending formal rehabilitation and did not want to join the study; two people identified time constraints and three people identified problems with travelling to the research setting. 39% of potential participants did not meet the inclusion criteria: co-morbidity (n = 15); more than 85 years (n = 2); MI score of less than 25 (n = 3); longer than 2 years post stroke (n = 6) and having a history of more than one stroke (n = 3). Outcome data was therefore obtained from 18 participants at baseline and from 17 at post-intervention and follow-up. One participant dropped out after baseline measures and one treatment session, despite efforts to reschedule appointments and to acquire further outcome data. 18 participants were recruited and randomised into either a VR mediated upper limb therapy group or the standard therapy group. See Table 1 for baseline characteristics. There were no significant differences between the groups at baseline. Outcome data were obtained from 95% of participants at the end of treatment and at follow-up. One participant withdrew consent after one VR session. Compliance in both groups was high, with all 17 participants completing all nine therapy sessions. Only two people reported side effects of transient dizziness and headache from VR exposure.

Group median scores indicated an improvement in MI scores for both groups, with the VR group sustaining that improvement during follow-up. Each intervention appeared to have been equally effective post intervention, with respect to the MI score. There was a positive trend in MI score in favour of the VR group at follow-up, with the ST group dropping back to baseline level. However for the functional test (ARAT) there was a positive trend in favour of the ST group at discharge from intervention. At follow-up the VR group had improved their performance on the ARAT. Both groups showed a similar level of change in ARAT by follow-up.

Table 1. *Baseline Characteristics of Participants.*

	VR Group	**ST Group**
Age (years) Mean (SD)	56.1 (14.5)	64.6 (7.4)
Sex	5 male, 4 female	5 male, 4 female
Time since stroke (SD)	10 months (6.4)	11.7 months (7.8)
Side most affected	4 left, 5 right	3 left, 6 right

The Friedman test indicated significant differences within both groups across the time points of the study for the upper limb MI score ($p = 0.008$) and the ARAT score ($p = 0.01$). The Mann-Whitney U test indicated no significant differences between the groups. There was a change of between 7-8 points for each group in the MI score, and of 3-4 points for the ARAT. The minimally clinical important difference for the MI has not been published; however other studies have identified a change of 10% in an outcome score as being clinically relevant (Brønfort and Bouter, 1999). This would represent a change of 10 points on the MI score. Thus the trend in these results would not be clinically significant. The MCID for the ARAT is 6 points [26], and likewise these results were not clinically significant.

Four of the nine VR participants reported that movement of the more affected arm had improved and that following participation in the trial could undertake some tasks that they had not been able to do previously e.g. driving a car; opening kitchen cupboards. Seven of the nine who received standard therapy reported that the movement in their more affected arm had improved. Difficulties were encountered in recruiting people with moderate to severe levels of disability.

8. CONCLUSION

This study demonstrated the feasibility of a randomized controlled trial of VR based therapy for the upper limb compared to standard therapy. The trial design was acceptable to participants. A power calculation for a larger trial indicated that 24 participants would be required in each arm in order to have the power to demonstrate statistically significant changes to both impairment and function of the more affected upper limb. This was calculated by using the MCID for the MI and the ARAT, and the standard deviations from this data.

The small sample sizes and the lack of sensitivity of the outcome measures for the population recruited are likely to have affected the results. It was disappointing not to have been able to recruit participants with a wider range of disabilities, with most scoring towards the ceiling of both outcome measures at baseline. Based on these preliminary results it is not yet possible to definitively advocate VR over standard therapy for the rehabilitation of the upper limb.

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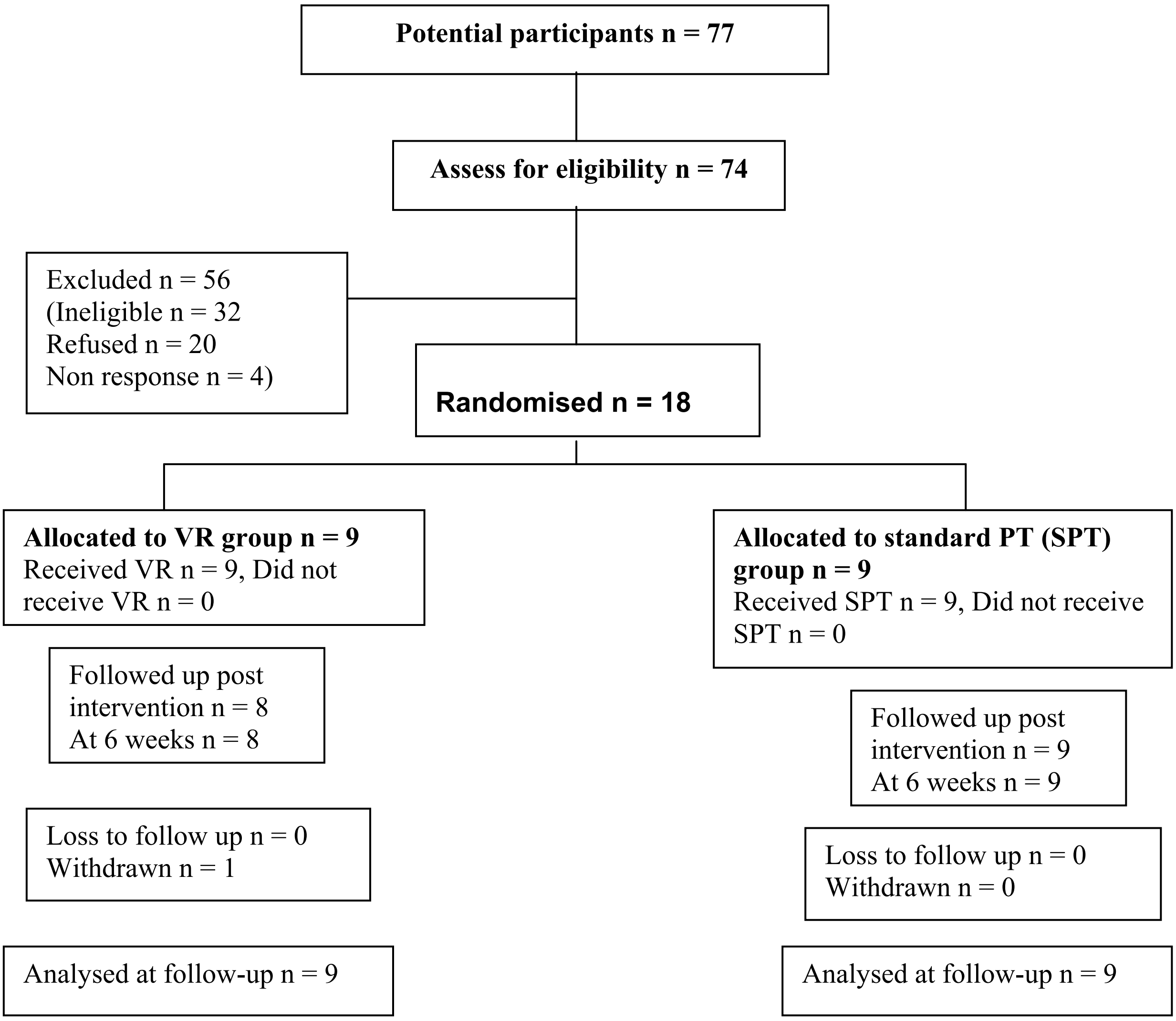

Figure 2. The flow chart of the trial according to the CONSORT statement (Moher et al, 2001).

HARMiS – Hand and arm rehabilitation system

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ABSTRACT

This paper presents the HARMiS device (Hand and arm rehabilitation system), which is primarily intended for use in robot-aided neurorehabilitation and for training of reaching, grasping and transporting virtual objects in haptic environments. System combines haptic interface and module for grasping, which is mounted on the top of the haptic interface. This allows combined training of the upper extremity movements and grasping. High level of reality is achieved with use of the graphic and haptic visual environments, which is beneficial for the motivation of the patients.

1. INTRODUCTION

Robot-aided neurorehabilitation is a sensory-motor rehabilitation technique based on the use of robot and mechatronic devices (Loureiro et al, 2004; Mihelj et al, 2007). Aim is to aid and augment the traditional therapy intended for patients with motor disabilities to improve the patient's motor performance, shorten the rehabilitation time, and provide objective parameters for patient evaluation (Harwin et al, 2006; Kahn et al, 2006). Measurements of forces and positions acquired during the tasks allow quantitative assessment of neuro-motor state of the patients and their progress. European project Gentle/s showed that subjects were motivated to exercise for longer periods of time when using an augmented virtual reality system composed of haptic and visual reality systems. Subjects could exercise "reach-and-grasp" type of movements but without the grasping component, which was identified as one of the shortcomings of the Gentle/s prototype. (Loureiro et al, 2004). With tasks implemented in virtual environments new quality is added if the tasks motivate and draw in the patient and also because apparatus allows to quantitatively evaluate the patient's state (Luciani et al, 2004; Kurillo et al, 2007).

Paper will present HARMiS device, which combines haptic device for upper extremity with a module for grasping and computer generated haptic and graphical virtual environments. The HARMiS device allows combined therapy for upper extremities and grasps rehabilitation. Joint therapy is reasonable because most of the activities of daily living require both arm movements and grasping (Fritz et al, 2005).

2. METHODS

2.1 *Apparatus*

HARMiS is based on a three-degree of freedom admittance controlled haptic interface HapticMaster (see Fig. 2). Completely new control algorithm for controlling the haptic interface arm was designed and implemented on RTLinux with 2.5 kHz sampling loop frequency. The adopted design paradigm allows implementation of a transparent custom-made robot controller. Custom-made robot controller allows building a custom made haptic virtual environments. Figure 1 shows the control algorithm, upper scheme shows the calculation of desired velocity v_{virt} and position p_{virt}, and lower scheme shows controller. End-point of the robot is represented with virtual mass point with mass m (in our case mass m was 3 kg). Forces that act on virtual mass point are measured force F_{meas} applied by the user and forces F_{VE} that act on the virtual mass point in virtual environment (force of the virtual wall, contact forces with virtual objects, etc). From sum of these forces the movement of the virtual mass point is calculated. From the velocity v_{virt} and position p_{virt} of the virtual mass point and actual position of the haptic interface p_{enc} reference velocity v_{ref} for the haptic interface

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HapticMaster is calculated, which is input in the PD controller. PD controller is analog controller and is part of the hardware supplied by the FCS Control Systems. Input of the controller is also measured force v_{tah}, which is compared with reference velocity v_{ref}, and the output is generated current I_{reg} for the motors of the haptic interface.

The two-axis gimbal with a two-degree of freedom grasp module mechanism and a wrist support splint is attached on the end-point of the robot. The gimbal is used to carry the weight of the subject's arm and the grasp system and to allow unconstrained movements of the subject's arm. The force sensor on the end-point of the robot is used for measuring the interaction forces between the subject and the haptic virtual environment.

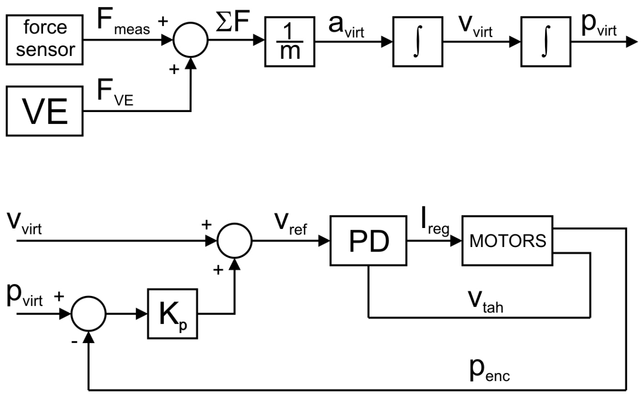

Figure 1. *Control scheme of the HARMiS device. Upper scheme presents the calculation of desired velocity v_{virt} and position p_{virt} from sum of measured force and forces of virtual environment. Lower scheme presents the control scheme of haptic interface HapticMaster.*

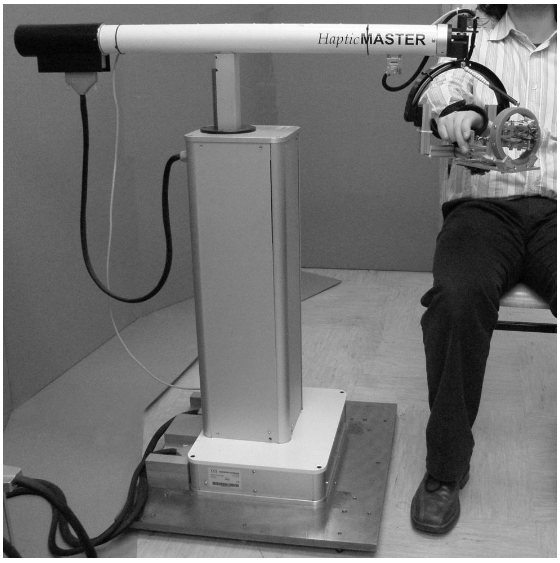

Figure 2. *HARMiS device. Figure shows haptic interface HapticMaster and the grasp module mounted on top of the robot arm. The user inserts the hand into the gimbal device which supports the arm.*

The grasp module (see Fig. 3) is a newly designed passive haptic system for grasping virtual objects in haptic virtual environment. It has two passive degrees of freedom each with a load cell for measuring grasp force, one for measuring the force applied by thumb and other for measuring the joint forces applied by index and middle finger. Passive haptic rendering was achieved by adding the elastic cord between the frame and the movable part of the grasp module. The grasp module can be quickly fully adapted to different sizes of hand, different levels of grasp force and for measuring on either left or right hand without a need to disassemble the grasp module.

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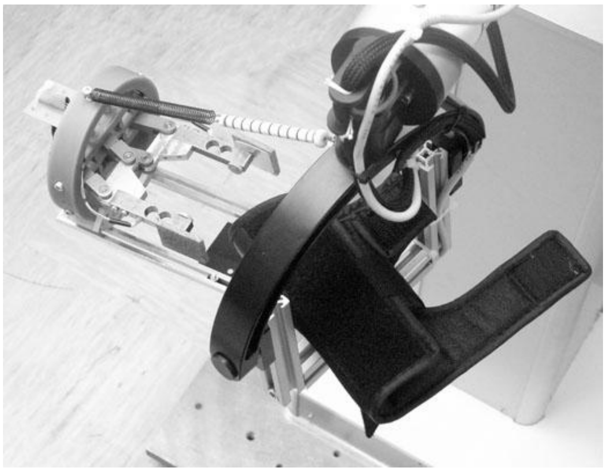

Figure 3. *Grasp module consists of gimbal device, a wrist support splint and two-degrees of freedom mechanism for measuring the grasp force and for passive haptic rendering.*

2.2 Pick and Place Task

In this task the subject must move arm to the virtual object and grasp it. Then the subject must transport it to the new location and releases it. When the object is released a new virtual object comes in to the workspace and the subject must again reach it and transport it to the new location. If the subject does not apply sufficiently large grasp force the object will fall down and will have to be picked up again. The virtual objects in this task were apples, which fall of the tree and the subject has to carry them on a fruit stand where the apples are sold (see Fig. 4).

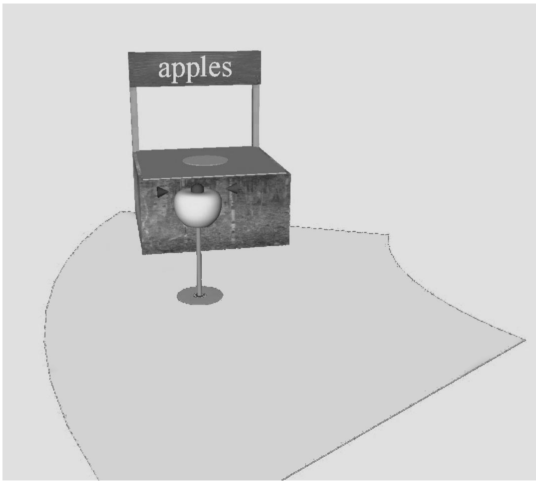

Figure 4. *Pick and place task in which the user is transporting apple on the fruit stand. Sphere represents the end-point position, while cones represent virtual fingers.*

2.3 Winded Tube

The aim of this task is to move through winded tube shown on the Fig. 5 and to navigate a virtual elastic ball through winded pipe, which covers major part of the subject's arm workspace. The radius of the pipe changes along the path of the tube. The position of the hand is represented with elastic ball. The radius of the elastic ball changes according to grasp force applied by the subject in similar manner as if the subject would be squeezing the actual rubber ball. At the start the radius of the ball is larger than the radius of the pipe and the user is required to apply sufficient grasp force to squeeze the ball to the radius which is smaller than the radius of the pipe. As the pipe gets wider or narrower over the course of the path through the pipe the subject has to "squeeze" the ball to appropriate radius if it wants to get to the end of the pipe. Whenever the subject does not apply sufficiently large force the walls of the pipe stop him because the radius of the ball becomes larger than the radius of the pipe. When this happens the user is required to increase the grasp force.

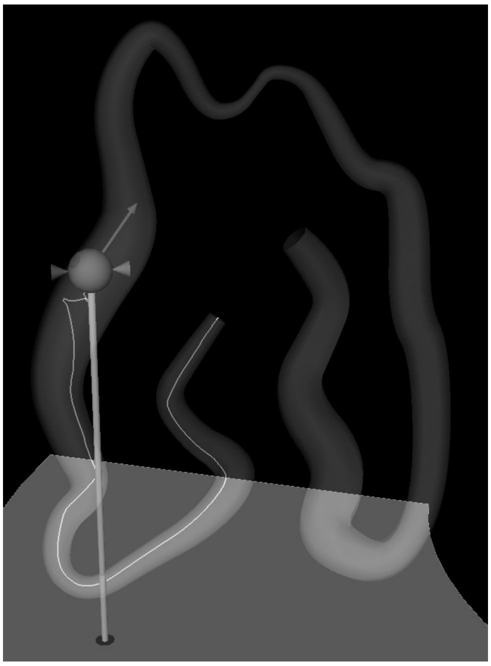

Figure 5. *Task winded tube. When the user applies the grasp force the radius of the ball will change according to grasp force applied.*

2.4 Subjects

Five healthy male, right-handed subjects (25–29 years old) participated in the present study. The participants had no history of neuromuscular or musculoskeletal disorders related to the upper extremities.

3. RESULTS AND DISCUSSION

3.1 Pick and Place Task

Figures 6, 7 and 8 show the grasp force, position and load force for 17 trials of transporting the virtual object. Figure 6 shows the grasp force. Figure 7 shows the position of the wrist. The grounds are on the height -0.18 m and the stand is the height -0.10 m. Figure 8 shows the load force. The load force is the force that acts on the wrist and is applied by the user's arm. The x-axis is shown in normalized time. Three time markers were chosen to divide transporting of the virtual object into phases:

- Preload phase. Forssberg et al (1991) has described basic mechanisms of coordination between grasp and load force in preload and load force in children and adult subjects. In preload phase we have observed small negative load force, which the Forssberg et al (1991) has observed in children but not in adult subjects. The subject gently presses the virtual object against the virtual ground and prepares for stable grasp. One could speculate that adult subjects in virtual environments employ mechanisms which are typical for early years of development of grasp to load force coordination in children. However, it is more likely that due to less rich sensory information available in virtual environments, the user compensates it with pressing the object to the ground to assure stable grasp.
- Loading phase. Both grasp force and load force increase to their maximum at about 0.20 of normalized time. In our experiments we can observe same lift synergies in grasp and load forces as in the case of lifting real objects as described by the Forssberg et al (1991). This shows that adult subjects, when lifting the object in virtual task, employ same anticipatory control of the force output during the loading phase as in real situation.
- Transporting phase in which the subject lifts the virtual object and transports it to a new location. The grasp force is slowly decreasing, but does not fall below the grasp force required to hold the virtual object. When object is lifted and held stationary, subject has to compensate only for the weight of the object and load force is constant. However, when object is moved inertial loads arise and result in increased load force. This increase can be seen in Fig. 8 as a second peak at about 0.65 of normalized time. When transporting actual objects held with fingers grasp force increases in parallel with load force (Flanagan et al, 1993; Nowak, 2004). In Fig. 6 it can be seen that in our experiments the increase in grasp force is not present. In experiments performed by Flanagan and Wing (1993) and recently

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Nowak (2004) the grasp force was force in normal direction and load force was force in tangential direction, fingers thus applied both forces. In our experiments the grasp force is force in normal direction and applied by fingers, while load force is force measured between the wrist and the end-point of the haptic interface. Hence, subject does not feel the perturbations with the fingers but on the wrist. Hence, the grasp force and the load force are decoupled. This was necessary for a successful use of HARMiS device as a rehabilitation device for upper extremity and grasp rehabilitation. The HARMiS device supports the subject's arm in the wrist, which is appropriate for upper extremity rehabilitation. The help provided by the haptic interface to the subject or a resistance will be set accordingly to subject's level of upper extremity impairment, while the grasp part of the task will be set accordingly to subject's level of grasp impairment. The HARMiS device is thus designed intentionally for use in rehabilitation with special emphasis on joint rehabilitation of upper extremity and grasp, and it can be adapted to special requirements of the patient's level of impairment. Transport phase ends at 0.9 of the normalized time when the subject puts down the virtual object on a new location.

- Release phase is the last phase in which the subject releases the virtual object.

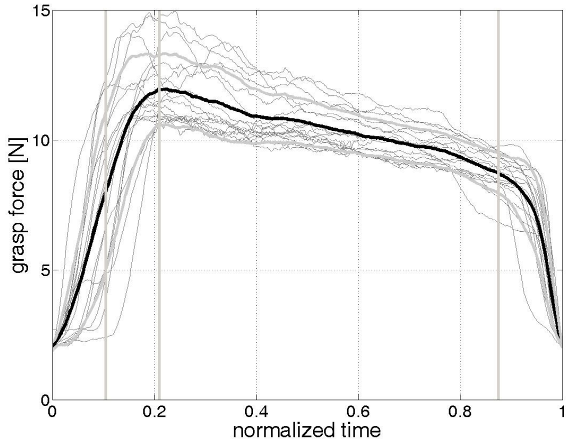

Figure 6. *Grasp force as a function of normalized time in task pick and place. Vertical lines denote time markers: first marker – end of preload phase and beginning of loading phase, second marker - beginning transport phase, third marker – beginning of release phase*

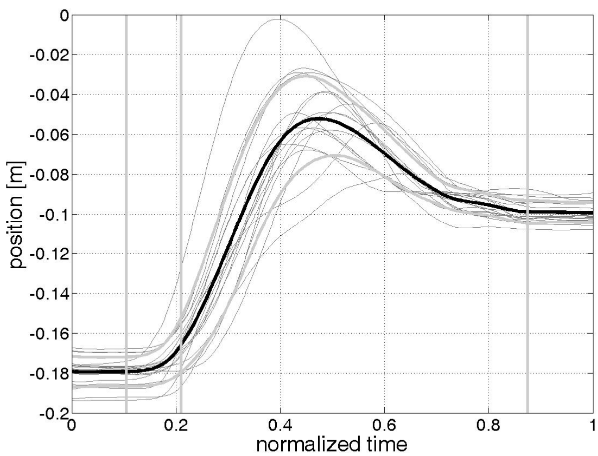

Figure 7. *Z-axis position of the wrist as a function of normalized time in task pick and place.*

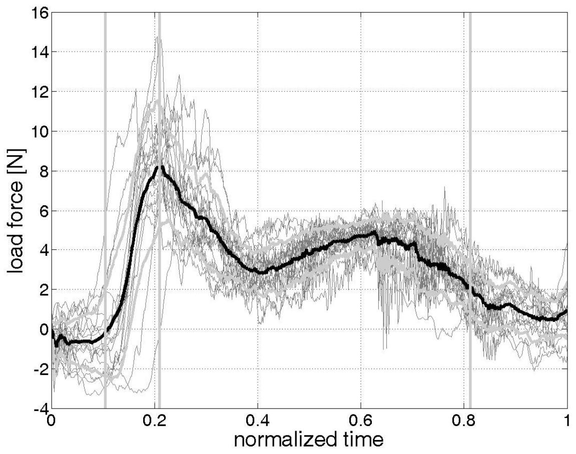

Figure 8. *Load force as a function of normalized time in task pick and place.*

3.2 Winded Tube

Figure 9 shows the trajectory through the winded tube (bold line) and the dimension of the ball (two thin black lines). The two most outer black thin lines represent the walls of the tube. Trajectory through the tube is colored in three different shades of grey to represent different ways the subject moved through the pipe. Black bold line represents the parts of the trajectory where the radius of the ball is larger than the radius of the pipe. The subject gets "stuck" in the pipe and has to increase the grasp force to continue through the pipe. Figure 10 shows the grasp force in the task winded tube. Grey field represents the minimum necessary grasp force required to get through the pipe. Grasp force is represented with bold black line when the grasp force applied by the subject is bellow the required grasp force and with dark grey line when the subject applies sufficiently large grasp force. Whenever the grasp force becomes lower than required grasp force the user increases the grasp force in order to again move freely along the pipe. Dark grey bold line in Fig. 9 represents the part of the trajectory when the radius of the ball is smaller than the radius of the pipe and the ball is in the contact with the wall of the pipe. Light gray bold line in Fig. 9 represents the part of the trajectory when the ball is smaller than the pipe and the ball is not in the contact with the wall. From the Fig. 9 it can be seen that the user slides along the pipe when moving through the pipe.

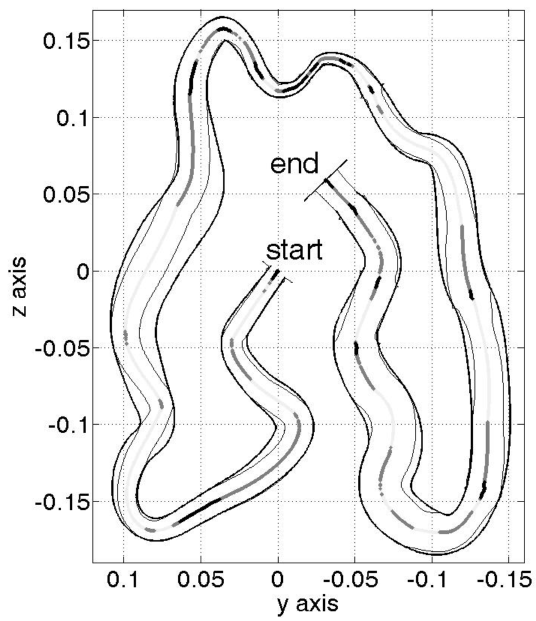

Figure 9. *Central bold line represents the trajectory of the ball. Light gray – the ball is not in the contact with the wall of the tube; dark grey – the ball is in contact with the wall of the tube; black – the radius of the ball is larger than the radius of the tube.*

This task also requires user to move the arm and use the hand to grasp. But it differs from the pick and place task, because the user has to change the grasp force during the task in accordance with the radius of the tube. In the pick and place task the user has to apply sufficiently large force for the stable grasp in the virtual environment. It is only required to reach the threshold grasp force which corresponds to the grasp force for stable grasp in virtual environment. This force is chosen before the task begins and it remains constant through the pick and place task. On the other side, in winded tube task the radius of the tube defines the minimum grasp force at a certain part of the trajectory through the tube. Hence, the winded tube task can be placed among tracking tasks (Wetherell, 1996; Jones, 2000), since the user is required to apply grasp force larger than the minimum grasp force which is the reference. However, the winded tube tasks introduces new modality since the user is not just tracking the visual reference, which is in case of winded tube the radius of the tube, but it also can feel the haptic stimulus. The user can apply larger grasp force than required, while if the grasp force is lower than minimal grasp force the user will feel that the ball got stuck in the tube and will have to apply much larger force with the arm to continue. Hence, the user will be compelled to increase the grasp force.

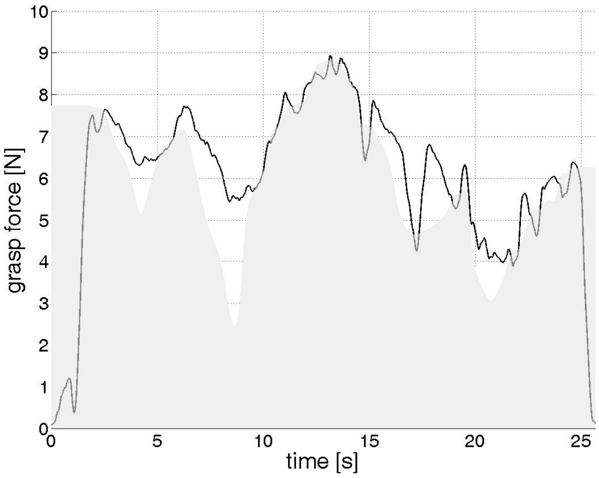

Figure 10. *Grasp force applied by the user in winded tube task. Grey field represents the minimal grasp force.*

4. CONCLUSIONS

System HARMiS described in this paper allows the therapy to be expanded to grasp treatment. The possibility to grasp objects in virtual environment introduces new level of tasks, which resemble even more to the activities of daily living. Hence, beside the elbow and shoulder movement treatment, the therapy can be expanded to grasp treatment and therapies can be carried out jointly at the same time. Subjects have also reported that the ability to grasp the objects in virtual environment gives them the feeling of more natural interaction with the virtual objects. Subjects have also reported that they feel more motivated to finish the task successfully. However, the system has several drawbacks. Grasp module is passive and can only render passive haptics. To improve the grasp module an active mechanism would be required. The preliminary experiments on healthy subjects showed that the two-degrees of current mechanisms could be coupled and one active degree would suffice.

The future work will also include patients with movement disabilities.

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Virtual reality, haptics and post-stroke rehabilitation in practical therapy

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ABSTRACT

We address the question of *usefulness* of virtual reality based rehabilitation equipment in practical therapy, by letting experienced therapists explore one such equipment during six months in their regular practice under natural circumstances. By protocols, questionnaires and focus group interviews we collect data regarding which activities they considered useful, why these are useful and what might improve usefulness of such activities, based on the therapists' professional judgement and experiences. This resulted in a set of purposeful activities, identified values for therapeutic work, and design guidelines. The conclusion is that such equipment has benefits beyond real life training, that variation in content and difficulty levels is a key quality for wide suitability and that the combination of challenging cognitive activities which encourage motor training was considered particularly useful.

1. INTRODUCTION

Stroke is the number one cause of adult disability and the third leading cause of death in the US (American Stroke Foundation, 2008). Globally, 15 million individuals per year get stroke (Internet Stroke Center, 2008). Moreover, stroke is a devastating condition that often results in serious long-term complications. Rehabilitation is mostly necessary and of long duration and even though clinical rehabilitation works well, home based or out-patient rehabilitation works less successful (Broeren et al, 2008). In this work, we therefore focus on out-patient rehabilitation in practical therapy, where most long-term rehabilitation work takes place.

Stroke can cause a wide range of cognitive as well as motor impairments. Cognitive impairments can affect comprehension, memory, visual recognition, attention, and task sequencing (Connor et al, 2002), as well as motor impairment such as reduced upper limb mobility, paralysis on one side or impairment in balance. Every stroke is different; therefore every stroke survivor is different (American Stroke Foundation, 2008), but most suffer from both cognitive and motor impairment. By providing training for both simultaneously, virtual reality (VR) can enhance stroke rehabilitation (Broeren et al, 2006; Broeren 2007; Goude et al 2007; Katz 2005; Kizony et al, 2004; Hilton et al, 2000; Hilton et al, 2002). Motor training can be provided by haptic force feedback interaction devices and cognitive training by tasks in the virtual environment.

In this study we address the question of *usefulness* of such VR-based rehabilitation equipment in practical therapy, raised by (Edmans et al, 2004) as the most important question. Our aim is not to determine whether particular equipment is useful or not, rather do an open-minded exploration of different aspects of usefulness perceived by experienced therapists in a natural usage situation. From their experiences, we then do an in depth analysis of *which activities are considered useful*, *why they are useful* and what might *improve* *usefulness of such activities*. As the relationship between motor and cognitive abilities is complex and interrelated (Kizony et al, 2004), we do not a priori look for example activities particular for training motor functions (as in Henderson et al., 2007; Sugarman et al, 2008), but take a holistic, "bottom-up" approach to usefulness including all aspects.

Hence, our results will primarily be based on the therapists' experiences and professional judgement of using the equipment. It has been claimed by Martin et al. (2006) that in particular developers of medical devices ought to incorporate user requirements into their development processes, since poor usability increases the risks associated with medical device usage. To understand usage, the often complex interplay between users (i.e., staff and patients), the medical equipment, the work task and the use environment need to be considered. It is within this context that the use qualities of the technology emerge and, consequently, where the requirements for the technology are defined (Karlsson et al, 2007). Shah and Robinson (2007) have identified benefits of user involvement which includes discovery of conceptual deficiencies and potential problems in current and future equipment; and to propose changes and solutions to these problems (Garmer et al. 2004). Furthermore, user involvement helps elicit user needs, opinions, expectations, and experiences that may prove critical to the deployment of a technical product (Luck, R. 2003)

The rationale behind occupational therapy is to promote recovery through purposeful activity (Edmans et al, 2004). In order to approach the complex notion of usefulness, we have taken the perspective of the therapists' interest, and therefore decomposed our research question in the following sub-questions:

i) What types of activities are considered purposeful (by practitioners and patients)?

ii) What value can such equipment have for therapeutic work (according to practitioners)?

iii) What usability issues are of particular concern for users with cognitive and/or motor deficits?

The purpose is to better understand practical issues regarding usefulness and usability of VR-enhanced stroke rehabilitation. The long-term goal is to develop a design theory for VR-enhanced stroke rehabilitation, including a classification relating activities with deficits to rehabilitate. Such theory can be used to design more useful rehabilitation support and to guide the design of further studies of rehabilitation effects.

2. RESEARCH APPROACH

This work is based on collaboration between researchers and developers of VR-based equipment for stroke rehabilitation, researchers of interaction design interaction technology usage, researchers as well as practitioners in physical and occupational therapy.

Our overall methodology is a user-centred approach to design (Dix et al, 1998; Preece et al, 2002), in a realistic setting (Beyer and Holzblatt, 1998), since practical usability issues require realistic settings (Wattenberg, 2004). A user-centred, iterative approach to design which involves users is crucial when designing for disabled (Dickinson et al , 2002; Dickinson et al, 2003; Wattenberg , 2004). For this research, we use an iterative model to collect experience from clinical practice, increase our understanding of usefulness and usability, develop the equipment accordingly, and re-evaluate in clinical practice.

To approach our research question, we have studied usage of a VR-based rehabilitation equipment under development during practical therapy. The study has the following characteristics: a non-specialist environment, a natural setting and usage over time. The reason we have chosen a non-specialist practice is threefold: (1) Previous studies of the equipment focused on laboratory or stroke-specialist settings (Broeren et al, 2006; Broeren 2007). (2) Most long-term treatment takes place in non-specialist organizations, and therefore the equipment must be usable in such organizations without specialist competence. And (3) general purpose therapists treat a wide range of patients which may allow for a broader perspective on value and usefulness. Even though stroke rehabilitation is the main purpose of the equipment, other patient groups may benefit from the same type of training. Therefore, the broader experience of these therapists may be valuable.

By a natural setting, we mean a setting which is as close to introductions of new equipment as possible. The therapists got a short introduction to the equipment, and were provided with available instruction material. There were no developers or researchers present during the use period, except as for contacts when technical support were needed. They were asked to use the equipment as they found appropriate, as one among other rehabilitation tools. It was used over an extended period of time, so that usage over time could be followed for various patients, which is important for evaluating for instance motivational effects of the new equipment.

3. THE EQUIPMENT

The studied equipment is a virtual reality workbench with a haptic, force feedback interaction device (Goude et al, 2007; Broeren et al, 2006), recently being commercialized (www.curictus.com). The environment provides a wide range of activities through a library of casual 3D games (casual game n.d., 2008). At present there are 15 games available, including Memory, Bingo, Space tennis, Master Mind, mimicking sound sequences and various games involving throwing balls and arrows to different targets. The games are steered with the haptic input device, which is a pen positioned under the glass surface in the middle (see fig 1) where the 3D picture is projected. The pen also gives haptic feedback such as feeling the force from throwing a ball or touching a surface.

The level of difficulty can be varied in most games, and there is an award system (points) judging the user's performance playing the game. There is also an assessment test – a point test (two left pictures in figure 2), judging the user's performance regarding trajectory path, precision, accuracy and velocity.

Figure 1. *The work bench.*

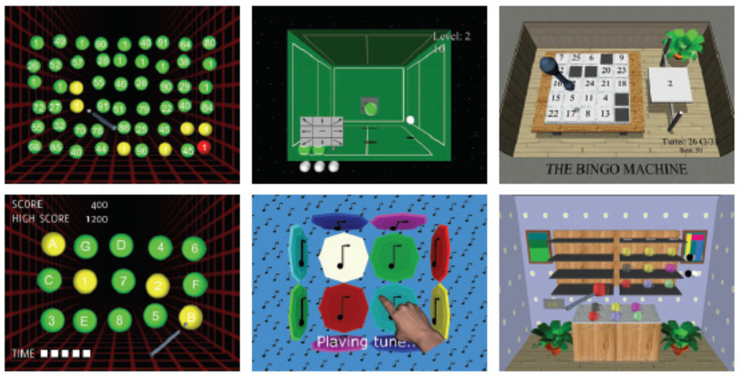

Figure 1. *Examples from game library menus.*
Top row: Assessment test, Space Tennis, Bingo
Bottom row: easier assessment test, Sound Sequence, Master Mind

Due to the variety offered, a game library is more appropriate for our exploration of purposeful activities than tailored activities such as coffee making (Hilton et al, 2002; Hilton et al, 2000) or street-crossing (Katz et al, 2005). Motivation is a success factor for rehabilitation (Edmans et al, 2004), and games are good for motivational purposes (Goude et al, 2007; Pareto 2007). Since motivation tends to decline by time, the variation of activities and the engagement game-playing yields are important aspects for long-term treatment.

4. THE STUDY

The study was performed in a small, general rehabilitation centre, deploying therapy for out-living patients. It lasted for 6 months and involved 2 physiotherapists and 1 occupational therapist. They participated by their own choice, because of interest in testing and evaluating this new rehabilitation equipment. They all had long professional experience in their respective profession, and were used to work together as a team. No one had prior experience with computer based rehabilitation support. During this period, they were provided with one prototype VR-based work bench of the type described above, which was placed in a room in the centre.

Since our aim was to find out as many different aspects of usefulness and usability issues as possible, we didn't want to restrict the use in any way. Therefore, we only showed the equipment to the therapists (how it was handled, which games it contained and how the assessment test was used), and then we let them try it out on their own for a while (see figure 3 below). They were provided with the user manual explaining basic information of how to operate the equipment, and short instructions to each game. They received no information of how the equipment previously had been used for rehabilitation purposes, neither any directions of what the different games could be used for. The only direction they got was to use it as they found appropriate. This was on purpose, since we wanted their evaluation to be truly explorative.

4.1 The Evaluation Procedure

The concrete evaluation procedure was designed in collaboration between the developer, the interaction design researcher and the involved therapists in a few meetings. The different parties' interests, available resources and time limitations were negotiated and resulted in the following procedure:

Figure 2. *One therapist testing the equipment.*

During the evaluation period, each therapist should offer the new training equipment to those of their regular patients as they judged the training appropriate for, not restricted to stroke patients. Thus, subject inclusion criteria were based on the therapists' judgement and knowledge of their patients solely, as common when introducing new equipment for rehabilitation training. The therapists designed an individual training program using the equipment for each subject, including personal status of abilities, purpose and goal of training, frequency and length of sessions and planned training period. Each subject was to take the assessment test regularly. Two protocols were developed, one for the individual training program, and one for each session to be filled out by the responsible therapists after the session. The latter included information on which games the subject choose to play, information about their performance (both measurements of assessment tests and subjective judgements by the therapist), problems with the games and the equipment and experiences of the usage during the session. The developer gave technical support when needed, on distance.

Each patient was interviewed by their therapist after the entire training period, regarding their experiences using the equipment. The therapists' and their patients' experiences as well as their professional judgements were collected in focus group interviews by the researcher in the middle and at the end of the evaluation period. Focus group interview is a suitable method for use elicitation (Garmer et al., 2004). The focus was on their different usages, patients' reactions and experiences, what was considered useful, what different features they used, problems and benefits with the equipment. The interviews lasted for half a day, and were recorded. The protocols were collected and analysed by the researcher, and the results were summarized, discussed and interpreted together with the therapists during the final interview. The therapists also summarized their use experiences for each game in a document, were they had identified valuable aspects of the games, problems and also gave suggestions of alterations and extension they would like to have.

Finally all collected data was synthesized into a set of activities identified as purposeful, a set of values identified for therapeutic work, and a set of design guidelines derived from the usability issues discovered during the evaluation period.

4.2 The Subjects

During the evaluation period, 15 regular patients were judged to be suitable for the training in question, and were therefore offered this new training method. They all tried the equipment, but three patients chose to stay with their current training methods. The remaining 12 subjects used the equipment according to their individual plan. Most subjects used the equipment for 1-2 hour sessions twice a week. Their respective training periods ranged from 3 to 12 weeks, depending on the remaining evaluation period and how long they wanted to proceed (for instance, one subject quit early due to family reasons). The age range varied from 20 to 85 years old, and was rather evenly distributed within that range. Four subjects were women and eight were men. Four subjects had other reasons for their disability than stroke. The non-stroke subjects suffered from fractures affecting upper limb mobility (2 subjects), burn injury or multiple sclerosis.

4.3 Next Design Iteration Cycle

The result from the evaluation has been used in the next cycle of the iterative design, in the continuing process of development the equipment. The developers wanted to extend the game library with new games dedicated to training stroke patients with neglect which is recognized as a deficit suitable to address by virtual reality (Kizony, 2004; Katz et al, 2005). For this purpose the design guidelines were used and refined.

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Two new games were designed, which are currently being integrated in the game library. Also, an interactive instruction video explaining usage was developed.

5. RESULTS

The study resulted in the following findings corresponding to the questions raised:

i) identification of purposeful activities in two categories: motor or cognitive training;

ii) identification of values for therapeutic work; and

iii) design guidelines particular for stroke rehabilitation equipment.

5.1 Purposeful Activities

The activities identified by the therapists are organized according to their main purpose. Purposeful activities for motor training include precision, speed and path directness in target finding; variation in hand angle or arm movements; speed control, strength control and rhythm; and combinations of the above. Tasks requiring both precision in direction and variation in strength were mentioned as one such useful combination. Also, the "repeat sound sequence" game was good since the sound buttons were located around all walls in the virtual room, so the user needed to twist the hand in different angles to reach them.

Purposeful cognitive training found in the games include hand-eye coordination; short concentration tasks; attention training; visual search; anticipation; depth perception; strategic planning and problem solving; and different combinations of these. In particular the hand-eye coordination was mentioned often as meaningful, since the user couldn't see their hand and had to sense the placement relative to the virtual room. The combination of strategic planning, reasoning and problem solving found in Master Mind was considered good training. Short concentration tasks such as remembering a played sound sequence, and games that required visual search all over the screen were considered to be purposeful training for many patients.

5.2 Values for Therapeutic Work

The values identified were mainly of two kinds: support to engage and motivate the patient and support for assessment. The variation of exercises and the engagement the game playing reached were appreciated, particularly for cognitive training. For assessment purposes, the objectivity in diagnostic tests, the support to judge cognitive abilities, and the support for performance and progress analysis were considered both new and valuable.

The equipment was considered useful for both cognitive and motor training, but the cognitive aspects were mentioned more often, in particular as a motivational driver for motor training. When asked about what was most important for playing the games, the cognitive or the motor ability, the therapists considered the cognitive aspect much more important for performance:

> *"If you have problem interpreting what to do, it does not matter how well you can steer the pen. The motor ability can be compensated by twisting the body or using the shoulder – if you know where to go."*

Also a patient stressed the cognitive aspect as important:

> *"I get to train motor functions and move the pen, and to all the time be alert and concentrate on what I'm doing, it does not work if I lose concentration no matter which game I play. The more I play the games, the more I think I improve all the time."*

5.3 Design guidelines particular for stroke rehabilitation equipment.

The design guidelines address the following areas: variability in content; difficulty level and speed; consistent behavioural simplifications of real world objects; ability levelled interaction schemas; multimodal feedback; performance and progress feedback; user appropriate instructions. In particular for long-term usage, the variation in content becomes crucial. The variability in difficult levels is one of the most important aspects, and can be applied to various parameters such as content (e.g., similarity in pictures in Memory), contrast (e.g., distinct back- and foreground or a diffuse naturalistic milieu), or required precision for targets.

These guidelines extend or are in accordance with the guidelines in (Hilton et al, 2000; Lövquist and Dreifaldt, 2006), except for the aspect of realism. Our study suggests that realism is not required, as long as behavioural simplifications are reasonable relative to real world experience. This can probably be explained by the difference in content: here a game environment is used, not a simulation of real world activities.

6. DISCUSSION & FUTURE WORK

The long-term ambition with the work bench is to make it suitable for patients' home-based training. For reaching this goal, a user-centred, iterative design process is crucial, and needs to be continued:

> *"Many patients needed a lot of supervision, we had to be with them all the time, so the equipment is not yet user-friendly enough – not for unsupervised home-based training."*

The practical evaluation in such early stage of development was much appreciated by the therapists:

> *"It is positive when someone is happy for all the errors we found, that's very unusual. But it was the purpose of this project – to make it [the equipment] user friendly before reaching the market. Often we receive new equipment and there are lots of things which are not good and we need to tell them [the developers], only resulting in a sigh: the product is finished."*

Our study design with a natural setting, long-term usage and explorative approach had several benefits. The natural setting with no third party present during usage, we believe was important for evaluating real usability issues: the presence of an equipment "expert" will consciously or unconsciously guide the users into pre-determined usage and thereby not discover other ways of acting with the tool. To study usage over time is important for evaluating attractiveness of activities and motivational effects. A one-time usage of 30 min (as for instance in Lövquist and Dreifaldt, 2006) can say very little about this quality.

The explorative setting with full user responsibility showed good potential for helping development progress. The users gave many valuable suggestions for improvement, as often is the case (Garmer et al. 2004), among those were:

> *"I would like to have a game which even more [than the sound sequence game] made the user twist her wrist and force using the hand in many different positions such as carve a bowl for instance."*
>
> *"I would love to have an assessment tool helping to judge suitability for keeping the driving license – we see patients who really shouldn't be driving a car, but since this is such an emotionally difficult restriction – it is hard to say something without a good ground for it."*

Finally, focus groups worked well for discussing different usages and viewpoints, as claimed by (Garmer et al, 2004), and generated many interesting discussions:

> "*We have seen different things, the three of us"*

6.1 Future work

Our long-term goal is to develop a design theory for VR-enhanced stroke rehabilitation. Here, we have studied perceived usefulness (Hassenzahl and Sandweg, 2004; Davies, 1989) and anticipated effectiveness with the purpose of informing future development of the technology. However, other types of studies are needed to confirm actual effectiveness. Also, actual usefulness must include consequences for real life transfer, which is increased ability due to rehabilitation efforts. This is a challenge to show, well illustrated by one patient's response to the question of improvements:

> *"It is difficult to say what exactly is the cause of a recovered ability, abilities just re-appear from time to time without any apparent reason."* (patient, 9 years after stroke).

7. CONCLUSIONS

Virtual reality with haptic force feedback has benefits beyond real life training:

> *"It is a good point that they can't see it [the hand], they cannot compensate the deep sensation of their hand by vision, they have to feel it. They may think the hand is positioned somewhere in the picture [virtual room], but the pen shows up elsewhere – oops".*
>
> *"One patient was extremely afraid of using her hand, but in front of the computer she completely forgot to be afraid".* (About patient with broken wrist)

Games as activity base are motivational beyond real life training:

> *"The scoring of the games is motivating – I could never get them to move around other [physical] things or play a [physical] move-around game for 45 minutes, as they did with the computer. One I had to throw out after 1 and ½ hour because I had to go home – they would never sit for 45 minutes so intensively!"*

"I think this is good actually, I have tried this during the summer about 15 times I think. In the end of each session I get a test, and then I should push the green dots as fast as possible… the time is measured and sometimes I do well and sometimes not so well. I'm trying to get below 30 seconds, I'm currently at 31,4…" (patient)

Variation of activities and levels is vital for attractiveness and wide suitability, due to patients varying abilities and taste: different patients liked and were capable of using different games at different levels:

"Space tennis was absolutely most popular. Memory was chosen by many also, and surprisingly had some difficulties that I didn't expect: Remember the positions, there are after all only 12, still they had problems finding the pictures. Bingo was also rather popular."

"The ones, who liked Spherix, have not been neurologically impaired, but they needed wrist mobility and coordination training. Suitable for motor impairment, if their cognitive ability is reduced they do not manage this game."

Particular the combination of challenging cognitive activitiess which encouraged motor training was considered useful:

"For cognitive and motor training of arms and hands, there is a market [for this equipment]. It gives possibilities to assess cognitive ability which we haven't had before."

"I will miss it. If we had it in the organisation, I could use it when I needed, that would have been great!"

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Robotic assisted rehabilitation in virtual reality with the L-EXOS

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ABSTRACT

This paper presents the results of a clinical trial employing the PERCRO L-Exos (Light-Exoskeleton) system, which is a 5-DoF force-feedback exoskeleton for the right arm, for robotic-assisted rehabilitation. The device has demonstrated itself suitable for robotic arm rehabilitation therapy when integrated with a Virtual Reality (VR) system. Three different schemes of therapy in VR have been tested in the clinical evaluation trial, which was conducted at the Santa Chiara Hospital in Pisa with nine chronic stroke patients. The results of this clinical trial, both in terms of patients performance improvements in the proposed exercises and in terms of improvements in the standard clinical scales which have been used to monitor patients progresses will be reported and discussed throughout the paper. The evaluation both pre and post-therapy was carried out with both clinical and quantitative measurements with EMG and motion data; the latter ones measured in terms of different kinetic parameters estimated through the online data logged during the repeated sessions of exercise. It is to be noted that statistically significant improvements have been demonstrated in terms of Fugl-Meyer scores, Ashworth scale, increments of active and passive ranges of motion on shoulder, elbow and wrist joints of the impaired limb, active and passive, and quantitative indexes, such as task time and error, synergies and smoothness of movement.

1. INTRODUCTION

Several research studies have recently focused both on the development of novel robotic interfaces and on the use of Virtual Reality technologies for neurorehabilitation. The former may overcome some of the major limitations manual assisted movement training suffers from, i.e. lack of repeatability, lack of objective estimation of rehabilitation progress, and the high dependence on specialized personnel availability. As a matter of fact, thorough and constant exercise has revealed itself essential to produce a significant therapy outcome (Diller, 2000). On the other hand, VR-based rehabilitation protocols may significantly improve the quality of rehabilitation by offering strong functional motivations to the patient, who can therefore be more attentive to the movement to be performed.

Several arm rehabilitation robotic devices, both Cartesian and exoskeleton-based, have been developed in the last 10 years. Some examples include MIT Manus (Krebs et al, 1998), (Fasoli et al, 2003), ARMguide (Reinkensmeyer et al, 2000), MIME (Mirror Image Movement Enabler) (Lum et al, 2002), 1-DoF and 2-DoF devices developed at Saga University (Kiguchi, Kariya et al, 2001), (Kiguchi, Iwami et al, 2003), ARMin-II (Mihelj et al, 2007) and Salford Exoskeleton (Tsagarakis and Caldwell, 2003). A recent survey (Prange et al, 2006) outlines that robotic-aided therapy allows a higher level of improvement of motor control if compared to conventional therapy. Nevertheless, no consistent influence on functional abilities has yet been found.

On the other hand, several studies (e.g. (Jack et al, 2001)) have demonstrated positive effects of Virtual Reality on rehabilitation, which enhances cognitive and executive functions of stroke patients (Cardoso et al, 2006) by allowing them to receive enhanced feedback on the outcome of the rehabilitation tasks he/she is performing. Moreover, VR can provide an even more stimulating videogame-like rehabilitation environment when integrated with force feedback devices, thus enhancing the quality of the rehabilitation (Stewart et al, 2006).

This paper presents the results of an extended clinical trial employing the L-Exos system (Salsedo et al, 2005), a 5-DoF force-feedback exoskeleton for the right arm; the system is installed at the Neurorehabilitation Unit of the University of Pisa, where it has been used in schemes of robotic assisted VR-based rehabilitation with 9 chronic stroke patients. In particular, three different schemes of therapy in virtual reality are presented in terms of control architecture and description of the task. This work is intended to extend previous works concerning a pilot study with the L-Exos system (Frisoli et al, 2007; Montagner et al, 2007) by providing significant therapy and clinical data from a much larger set of patients. The experimental results of a preliminary evaluation conducted with one patient and with healthy subjects are then reported and discussed. Moreover, other preliminary results from a pilot study which is currently taking place with the L-Exos are reported and discussed.

Section 2 presents a general description of the L-Exos system, underlining the main features which make the device useful for rehabilitation purposes, and a description of the developed VR applications may be found in Section 3. Section 4 and Section 5 discuss the main results which have been obtained with the L-Exos both in terms of improvements in the metrics used to assess patient performance in the therapy exercises and in terms of improvements in the standard clinical scales which have been used to monitor patients progresses. Conclusions and perspectives opened by this pilot study are briefly reported in Section 6.

2. L-EXOS SYSTEM

L-Exos (Light Exoskeleton) is a force feedback exoskeleton for the right human arm. The exoskeleton is designed to apply a controllable force of up to 100 N at the center of the user's hand palm, oriented along any spatial direction and it can provide active and tunable arm weight compensation. The device mechanical structure has been extensively described in (Frisoli et al, 2005), whereas a description of the model of its novel tendon transmission may be found in (Marcheschi et al, 2005).

The structure of the L-Exos is open, the wrist being the only closed joint, and can therefore be easily wearable by post-stroke patients with the help of a therapist. In order to use the L-Exos system for rehabilitation purposes, an adjustable height support has been created, and a chair has been placed in front of the device support, in order to enable patients to be comfortably seated while performing the tasks. The final handle length is also tuneable, according to the patient's arm length.

After wearing the robotic device, the subject's elbow is kept attached to the robotic structure by means of a belt. If necessary, the wrist may also be tightly attached to the device end-effector by means of a second belt, which has been used for patients who are not able to fully control hand movements. A third belt can easily be employed in order to block the patient's trunk when necessary.

The L-Exos device has been integrated with a projector used to display on a wide screen placed in front of the patient different virtual scenarios in which to perform rehabilitation exercises. The VR display is therefore a mono screen in which a 3D scene is rendered. Three Virtual Rehabilitation scenarios have been developed using the XVR Development Studio (Ruffaldi et al, 2006). The photo shown in Figure 1 has been taken during a therapy session, while one of the admitted patients was performing the required exercises, and is useful to visualize the final clinical setup.

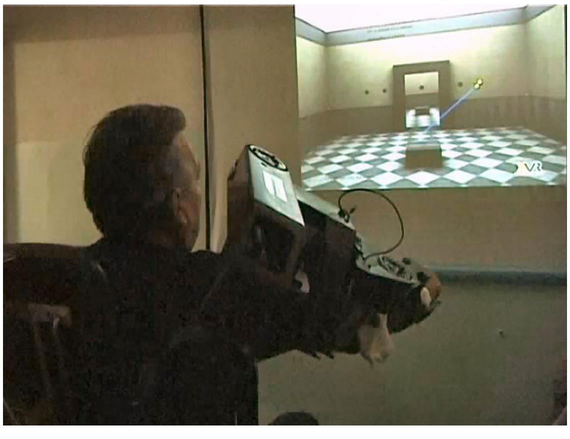

Figure 1. *Admitted patient performing the robotic-aided therapy exercises.*

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3. CLINICAL PROTOCOL

An extended clinical study involving 9 subjects pilot study with the main objective of validating the implemented therapeutic schemes and generally of evaluating the robot aided therapy with the L-Exos system has been carried out at the Santa Chiara Hospital in Pisa, Italy, between March and August 2007. Potential subjects to be enrolled in the clinical protocol were contacted by clinicians in order to ask for a possible interest in robotic-therapy and to take part in a preliminary test session used to evaluate patients acceptance of the device. Most of the patients gave an enthusiastic positive feedback about the opportunity.

Patients who were declared fit for the protocol and agreed to sign an informed consent form concerning the novel therapy scheme were admitted to the clinical trials. The protocol consisted of 3 one-hour rehabilitation sessions per week for a total of six weeks (i.e., 18 therapy sessions). Each rehabilitation session consisted in three different VR mediated exercises. A brief description of the goal of each exercise will be provided in the next paragraphs, whereas a more detailed description of the VR scenarios developed may be found in previous works (Frisoli et al, 2007; Frisoli et al, 2005). Some relevant control issues concerning the proposed exercises will be reported as well.

The patient is sat down on a seat, with his/her right forearm wearing the exoskeleton and a video projector displaying frontally the virtual scenario. A preliminary clinical test has been conducted to evaluate the ergonomics of the system and the functionality as a rehabilitation device on a set of three different applications. The test was intended to demonstrate that the L-Exos can be successfully employed by a patient and to measure the expected performance during therapy.

To assess the functionality of the device, three different tasks and corresponding exercises have been devised and are presented in three different sections: reaching task, free motion task constrained to a circular trajectory and task of object manipulation. The tasks are thought in order to be executed in succession within one therapy session of the duration of about one hour, to be repeated three times for week.

3.1 Reaching Task

In the first task, the represented scenario is composed of a virtual room, where different fixed targets are displayed to the patient as gray spheres disposed on a horizontal row, as shown in Figure 2. The position of the hand of the patient is shown as a green sphere, that is moved according to the end-effector movements.

When one of the fixed targets is activated, a straight trajectory connecting the starting point and the final target is displayed in the simulation. The patient is instructed to actively follow the position of a yellow marker, whose motion is generated along the line connecting the start and end points according to a minimum jerk model (Reinkensmeyer et al, 2000).

The patient is asked to move the arm to reach the final target with a given velocity, minimizing the position error between the yellow marker that moves automatically toward the target, and his/her own marker, represented by the green sphere. The yellow marker reaches the target with zero velocity, and comes back on the blue line towards the initial position. The patient is alerted of the start of the exercise by a sound, that is generated automatically by the system. The therapist can set the maximum speed of the task, by choosing among three maximum speeds (v_1 = 5 cm/s, v_2 = 10 cm/s and v_3 = 15 cm/s) and change the position of the fixed targets that should be reached by the patient, both in terms of target height and depth within the virtual room.

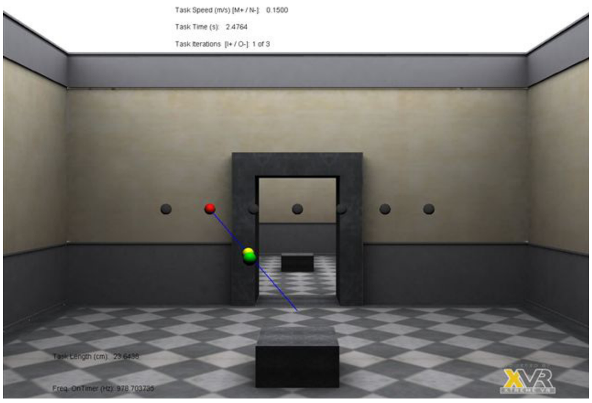

Figure 2. *The virtual scenario visualized in the reaching task.*

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3.2 Path Following Task

In the second exercise the patient is asked to move freely along a circular trajectory, as shown in Figure 3, where it is constrained by an impedance control. The virtual constraint is activated through a button located on the handle. Position, orientation and scale of the circular trajectory can be changed online, thus allowing the patient to move within different effective workspaces. No guiding force is applied to the patient's limb when he/she is moving within the given trajectory, along which the patient is constrained by means of virtual springs.

Also in this task the therapist can actively compensate the weight of the patient's arm through the device, until the patient is able to autonomously perform the task.

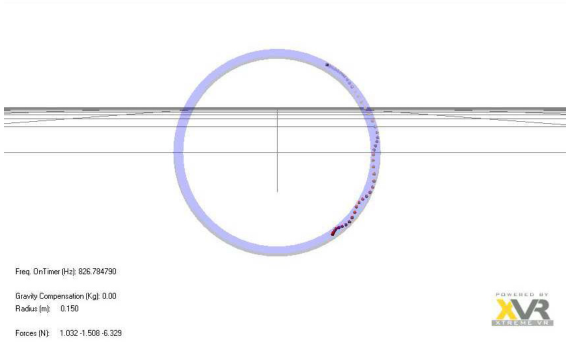


Figure 3. *Example of the free motion constrained to a circular trajectory.*

3.3 Free Motion Task

In this task the patient is asked to move cubes represented in the virtual environment, as shown for instance in figure 4, and to arrange them in a order decided by the therapist, e.g. putting the cubes with the same symbol or with the same color in a row, or putting together the fragments of one image.

For this task the device is controlled with a direct force control, with the interaction force computed by a physics module based on the Ageia PhysX physics engine (http://www.ageia.com/). By pressing a button on the handle, the patient can decide to select which cube wants to move and release the cube through the same button. Collision with and between the objects are simulated through the physics engine, so that it is actually possible to perceive all the contact forces during the simulation.

Also in this task the device can apply an active compensation of the weight of the patient arm, leaving to the therapist the possibility to decide the amount of weight reduction.

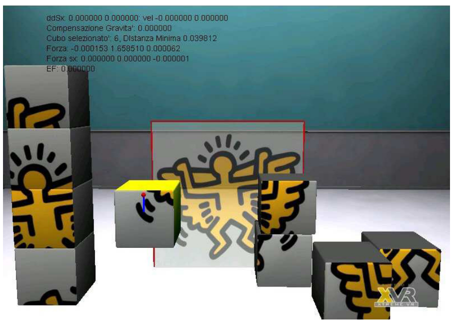


Figure 4. *An example of task of manipulation of objects.*

4. THERAPHY RESULTS

The following paragraphs will describe the metrics used in order to quantitatively evaluate patients' performance in the reaching task and in the path following task exercises. It is to be noted that no quantitative data has been computed for the last proposed task. A first obvious possible quantitative measure, such as task completion time, was thought as being not significant to evaluate patient performance improvements. This was due to the high variability in the task difficulty among different therapy sessions (initial cube disposition was randomly chosen by the control PC), and to the high variability in patient's attitude to consider the exercise as completed, i.e. the accepted amount of cube misalignment and hence the amount of time spent in trying to perform fine movements to reduce such misalignment.

4.1 Reaching Task

Figure 5 shows a typical path followed by a patient during the reaching task. The cumulative error for each task has been chosen as being the most significant metric to analyze reaching data. After the definition of a target position and of a nominal task speed, the cumulative error in the reaching task is computed for iterations corresponding to the given target position and speed. The cumulative error curves are then fitted in a least square sense by a sigmoid-like 3-parameter curve, represented by Eq. (1), where s is the cumulative error at time t, whereas a, b and c are fitting parameters.

$$s(t) = \frac{a}{1 + e^{(t-b)/c}} \tag{1}$$

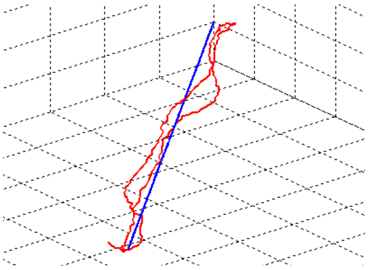
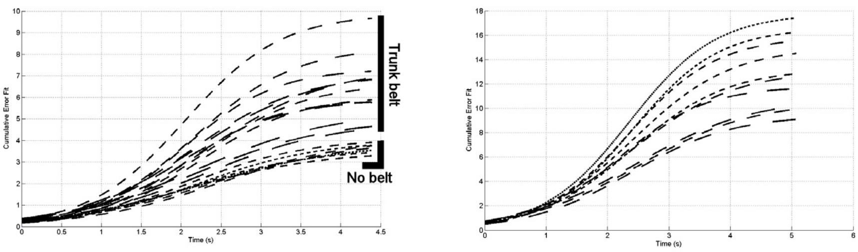


Figure 5. *Typical path followed during a reaching task – Blue: ideal trajectory, Red: actual trajectory.*

Fitting curves are then grouped and averaged on a therapy session basis, each set containing the fitting curves computed for a single rehabilitation session. Sample data resulting from this kind of analysis are shown in Figure 6, where a greater dash step indicates a later day when a given target was required to be reached with a given peak speed.

It is to be said that statistically significant improvements in the average fitting curves from Week 1 to Week 6 are recognizable for more than half targets in only 4 out of 9 patients enrolled in the protocol. A typical improvement pattern for a sample target is shown in Panel A of Figure 6 for Patient 6. This patient is constantly improving his performance in the exercise, leading to a significant decrease in the final cumulative error for a given target. A reducing of the mean slope of the central segment of the fitting curve is therefore present, thus indicating a higher ability to maintain a constant average error throughout the task.

Panel B of Figure 6 reveals an interesting aspect of the application of the belt used to avoid undesired back movements. During the first therapy sessions, no belt was present, and each therapy session registered a comparable value of the cumulative error. As soon as the trunk belt is introduced, the error increases dramatically, as formerly employed compensatory strategies are not allowed. However, due to the fact that active patient's movements become much more stimulated, the cumulative error fitting curve improves significantly. It is to be noted that, by the end of the therapy, values which are nearly comparable to the ones obtained in the no-belt condition are reached.



A B

Figure 6. *A: sample reaching results for Patient 6; B: sample reaching results for Patient 3.*

4.2 Path Following Task

Total time required to complete a full circular path was the quantitative parameter used to assess patient improvement for the constrained motion task. 3D position data have been projected onto a best fitting plane (in the sense of least squares), and the best fit circle has been computed for the projected points. Time to complete a turn was then evaluated with regard to trajectory. Curvature along the trajectory, which is irregular for the three patients, was not evaluated. In particular, due to the deliberately low value of the stiffness which realizes the motion constraint, patients sometimes move in an unstable way, bouncing from the internal side to the external side of the trajectory and vice versa, requiring some time to gain the control of their movements again. This behavior has detrimental effects on curvature computation.

Although three of the patients report no significant decrease of the completion time from Week 1 to Week 6, three patients report a decrease of about 50% in the task completion time, whereas other three patients report a decrease of about 70% of the same performance indicator. Such results are significant from a statistical point of view ($p < 0.001$ for the t-Student test for each patient showing improvements).

Sample data from Patient 3 are shown in Figure 7, in order to visualize a typical trend which has been found in the patients reporting improvements in the motion constrained exercise. It is interesting to note that, along with the significant reduction in the mean time required to complete a circle, a significant reduction of the associated standard deviation is recognizable, hence suggesting an acquired ability of performing the exercise with a much higher regularity level.

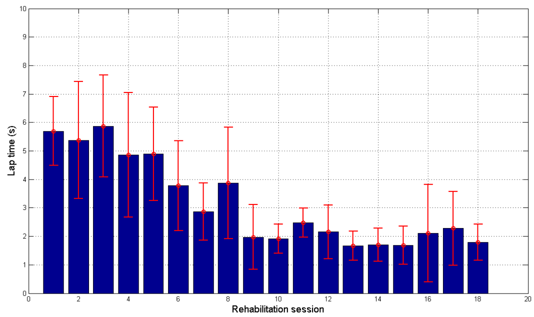


Figure 7. *Sample constrained motion task results – Patient 3.*

5. CLINICAL RESULTS

All patients have been evaluated by means of standard clinical evaluation scales and clinical improvements in each scale have been observed by the end of the therapy protocol for every patient.

5.1 Fugl-Meyer Assessment

Fugl-Meyer scale is used for the evaluation of motor function, of balance, and of some sensation qualities and joint function in hemiplegic patients (Fugl-Meyer et al, 1975). The Fugl-Meyer assessment method applies a cumulative numerical score. The whole scale consists of 50 items, for a total of 100 points, each item being evaluated in a range from 0 to 2.33 items concern upper limb functions (for a total of 66 points) and are used for the clinical evaluations.

Every patient reported an increment ranging from 1 to 8 points, 4 points (out of 66) being the average increment. Such results is absolutely comparable with the results which may be found in the scientific literature (Tsagarakis et al, 2003). A paired t-Student test on the significance of the increments in the Fugl-Meyer scale leads to a result of $p = 0.003$. The increments are therefore significant from a statistical point of view.

5.2 Modified Ashworth Scale

Modified Ashworth scale is the most widely used method for assessing muscle spasticity in clinical practice and research. Its items are marked with a score ranging from 0 to 5, the greater the score, the greater being the spasticity level. Only patients with modified Ashworth scale values ≤ 2 were admitted to this study.

Slight decrements of some values of the Modified Ashworth scale may be found examining detailed clinician assessments. The following improvement index has been defined for each value of the Ashworth scale:

- +1: decrement of one step (e.g. from 1 to 0/1);
- +2: decrement of two steps (e.g. from 1+ to 0/1);
- +3: decrement of three steps (e.g. from 1+ to 0);
- -1: increment of one step (e.g. from 1 to 1+).

The total improvement index has been computed for each patient. A mean improvement of 6.2 points in the overall improvement index has been found, with a standard deviation of 4.2 points. It can therefore be asserted that the robotic therapy with the L-Exos device leads to improvements in patients' spasticity levels.

5.3 Range Of Motion Evaluation

Range Of Motion is the most classical and evident parameter used to assess motor capabilities of impaired patients. Many ROM measurements have been performed by the clinicians collaborating in the protocol. Statistical significance data elaborations on total ranges have been performed by means of the paired t-Student test. Marginally significant or nonsignificant improvements have been found for passive ROMs, whereas each active ROM improvement is at statistically significant. This observation confirms that the therapy with the L-Exos has beneficial effects on the maximum range of motion both for joints directly employed when performing the therapy exercises and for joints not directly exercised by the rehabilitation exercises (e.g. wrist) and blocked in a fixed position during the therapy. This evidence supports the theory stating that a dedicated shoulder or elbow therapy and the resulting neural repair of cerebral areas involved in proximal segments motor control may lead to a natural neural repair of cerebral areas involved in distal segments motor control.

Further evidence supporting such theory is provided by a single patient who reports unexpected significant improvements in hand movements. In particular, he is now able to control finger opening and closing motions at a slow speed, whereas he had not been able to perform any hand movement after the Cerebrovascular Accident. It is to be noted that no hand movements are employed in any exercise performed with the L-Exos system, due to the fact that hand and wrist are blocked in a fixed position with respect to the forearm throughout the therapy.

6. CONCLUSIONS

The L-Exos system, which is a 5-DoF haptic exoskeleton for the right arm, has been succesfully clinically tested in a study involving nine chronic stroke patients with upper limb motor impairments. In particular, the extended clinical trial presented in this paper consisted in a 6-week protocol involving three one-hour robotic-mediated rehabilitation sessions per week.

Despite most of the patients enthusiastically report major subjective benefits in Activities of Daily Life after robotic treatment, it is to be said that no general correlation has been found yet between such reported benefits and performance improvements in the proposed studies. In other words, patients who improve on the reaching task exercise may fail to present a corresponding performance improvement in the path following task and vice versa, and this does not seem to be correlated to the generalized extremely positive qualitative feedback. This observation may be caused by a variety of factors and requires further studies to be conducted.

Nevertheless, qualitative subject feedback is strongly supported by the clinical analyses which definitely underline significant improvements in clinical metrics deriving from robotic-mediated rehabilitation therapy, thus suggesting the possible need for more complex metrics to be used in order to analyze exercise performance. In particular, significant ROM increments for joints which are not actively exercised by the robotic therapy is considered an extremely important result. As a matter of fact, global cortical reorganization involving upper limb can be positively stimulated by exoskeleton devices like the L-Exos, even though some limitations in terms of number of DoFs are present. Further differentiated clinical studies will be conducted in order to evaluate which kind of robotic-assisted therapy is able to provide the best possible rehabilitation outcome.

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ICDVRAT 2008

Session VII

Visual & Hearing Impairment

Chair: Lindsay Evett

Remote mobility and navigation aid for the visually disabled

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ABSTRACT

Outdoor tests of a system for remote guidance of the blind are reported in the paper. The main idea of the system is to transmit a video stream from a camera carried by a visually impaired user to a remote assistant that navigates the blind by short spoken instructions. The communication link is established over the GSM network within the High-Speed Downlink Packet Access (HSDPA) communication protocol. Mobility trials of the system were carried out with a mobile prototype and three blind volunteers in the university campus. The aim of the study was to test the overall tele-assistance concept including: communication link efficiency and reliability, influence on mobility and safety, and the improvement of operator-user interaction. Tests, albeit performed on a small group of volunteers, clearly show an objective performance increase when traveling with the remote guide. This is evident primarily in increased travel speeds and decreased occurrences of missteps and collisions.

1. INTRODUCTION

Blindness deprives humans of their most important sense and the primary source of information about the environment. In Europe 3-4 persons in every 1000 are visually handicapped. This statistic is going to worsen, chiefly due to the aging demographic. The number of the blind in the world is foreseen to increase by 20% within the next 50 years (European Blind Union).

A blind person has to count on a sighted guide's help or use specialized aids that compensate for the lost vision. There are a numerous technical aids that have been developed through recent decades that make the lives of the blind easier. Braille monitors "print" the text that is legible for the blind. Sound synthesizers convert text into speech. Braille typewriters or electronic voice recorders facilitate the blind in tasks of storing text or spoken messages. Also, special software packages are being developed that make computers and mobile devices more friendly for the blind user. Hence, the communication barrier that the blind is confronted with is steadily being overcome. The blind, however, rank the lack of independent and safe mobility as the most important impairment that deprives them of normal everyday live, both social and professional wise.

There has been a long lasting research record on electronic travel aids (ETAs) helping the blind in obstacle avoidance and navigation. The idea of sensory substitution, i.e. replacing lack of stimuli from one sense by appropriate stimuli for another sense is in fact the operation principle of all ETAs for the blind (Bourbakis, 2008).

Among the reported ETA devices (some commercially available) one could indicate UltraCane (Sound Foresight), LaserCane (Nurion-Raycal), Sonic Pathfinder (Perceptual Alternatives), NavBelt system (Shoval et al, 2003), vOICe (vOICe), EAV (Espacio Acustico Virtual), Tyflos (Bourbakis, 2008), and our system based on stereovision and spatialized sounds for presentation of obstacles (Strumillo et al, 2006; Pec et al, 2006; Bujacz and Strumillo, 2006). However, none of these systems have found ubiquitous acceptance among the blind community, mainly due to high costs and long learning curves.

Another line of research on ETA devices that we have commenced a few months ago is aimed at navigating the blind by a remote sighted guide (Naviton). The underpinning idea of this study is that a blind pedestrian can be guided by spoken instructions from an operator who receives a video stream from a camera carried by the blind user. We have constructed an early prototype system comprised of a notebook worn in a backpack designed for mobility, a standard wireless LAN connection, a digital webcam mounted on a chest-strap, and a headset. Existing commercial software – Skype was used for audio and video streaming between the user and the operator. Results of tests that have been carried out indoors with three blind volunteers were reported in (Bujacz et al, 2008) and can be summarized as follows:

- contrary to their expectations, the blind participants retained better orientation when using the remote guide, than when walking unguided or with a human guide,
- average travel speeds were 20-50% better than following the paths unguided,
- the blind participants pointed out the psychological comfort and confidence brought by the contact with the remote operator.

In this communication we report results of implementing the concept of the remote navigation system for outdoors trials. Several field test scenarios were carried out on the university campus. The prototype was replaced by an ultraportable Flybook laptop and augmented with a GPS sensor. A new software package for streaming video, audio and GPS readouts over the GSM channel has been developed and tested. The trials were conducted with participation of the same three blind persons that earlier took part in the indoor tests.

Tele-assistance is a new concept to navigating the blind. Although, another person is still involved in the guidance, this idea has a number of advantages (e.g. increased user privacy and independence) over traditional guidance by a sighted person. Current and upcoming advances in information and telecommunications technologies offer platforms for efficient implementation of such systems.

To the authors' best knowledge, the system developed at the Brunel University, UK was the first reported system for remote guidance of the blind (Garaj et al, 2003). The system offered the tele-assistance service by implementing GPS and GIS technologies and transmission (voice, video, other data) over the 3G network. First successful guidance results were reported in an outdoors trial. A French company Ives Interactivity Video & Systemes has announced a device called Visio.assistant (Ives). It underwent preindustrial tests. In that solution the webcamera and the wireless transmitter are mounted in a case resembling hand hair dryer and the trasmission link is established over the WiFi network. Yet another tele-assistance system for remote guiding of the blind is the MicroLook, that is under development by a Polish company Design-Innovation-Integration (Microlook). MicroLook integrates a webcamera with a headset and a mobile telephone platform. The project is at the stage of a prototype under tests and was not published in any scientific literature; however, it has won a Brussel Eureka 2007 trade fair award.

2. PROTOTYPE DESCRIPTION

The prototype device consisted of an ultra mobile laptop computer (Flybook) worn in a shoulder bag, a digital webcam and a GPS receiver attached to the shoulder strap, and a single-ear head-phone with a microphone. The Flybook was equipped with a built in UMTS/HSDPA modem and a large touch screen. The digital webcam was a high-end Logitech camera, modified with a wide-angle fish-eye lens from a CCTV camera. The GPS receiver used Bluetooth to connect to the Flybook.

Using the ultra mobile laptop allowed the prototype to be both functional and easily modifiable, retaining access to all PC transmission protocols and codecs. The computer operated by the assistant who remotely aids the visually impaired person, can be any PC with a public IP address. A link is established over the Internet and GSM network using the HSDPA protocol.

2.1 Modifications from the Previous Prototype

The main modifications from the trials described in (Bujacz et al, 2008) were the change of the base platform from a laptop to an ultra-mobile laptop and the implementation of new software written for minimized delay of audio and video transmissions and quick automatic connections and reconnections. There also were a few smaller problems that were fixed or improved on. The camera was fitted with a fish-eye lens to broaden the operator's field of view. The audio headset was replaced by a single earphone-microphone set. During preliminary trials the camera's oversensitivity to sunlight turned out to cause many difficulties to the operator. This was solved by replacing the camera with a newer model that had the ability to automatically adjust exposure time.

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2.2 User-operator Connection

In the prototype, the connection can be invoked both by the operator and the blind user. The link is established through TCP/IP packets that guarantee information delivery. The status of the connection process is accompanied by appropriate auditory icons, i.e. calling in progress, connection established, connection failure, broken connection. The connection details are presented in Figure 2. The two feedback loops at the bottom of the schematic serve to calculate packet delays and trigger pauses in transmission if the network is too congested.

Figure 1. *Trial participant wearing the prototype for communication with a remote assistant: A – earphone, B - microphone, C – Bluetooth GPS receiver, D – webcam with a fish-eye lens, E – Flybook laptop with built-in UMTS/HSDPA modem and touchscreen.*

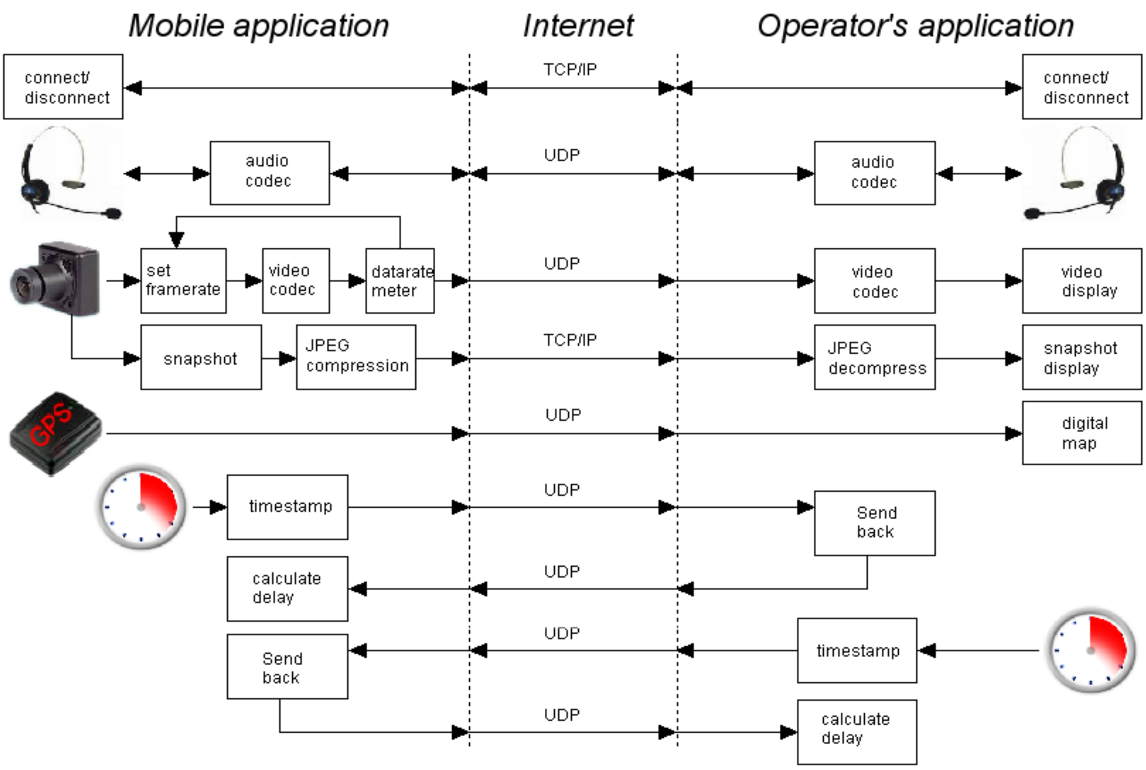

Figure 2. *The connection schematic and protocols used.*

The operator and the blind person establish a two way voice communication. Voice is sampled, 8-bit encoded and divided into appropriate data packets. The counterpart system receives the voice packets and decompresses them. Voice samples make their way to the destination by UDP packets that are devoid of any additional wrap-up data (compared to TCP/IP packets). Voice packets are made as compact as possible to arrive at the destination with minimal delay. In the current version silent samples are also transmitted, but an algorithm that skips such packets is in the works, as it will allow us to conserve a lot of bandwidth. The audio stream currently occupies approximately a constant bandwidth of 6 kB/s. Lost audio packets were not retransmitted. Packets' delay is kept at minimum mainly by a roundtrip packet monitoring procedure which is discussed thereinafter.

The blind person wears a digital USB camera. The acquired video sequence is compressed using the MPEG2 codec. The paramount issue of concern here is to fit the resultant stream (video and audio) below the canal throughput. Otherwise, packets are queued at the internet provider and in consequence the delivery is deferred. As mentioned before, the audio stream is constant. Hence, the video stream is the one modified not to exceed a given bandwidth. The volume of the compressed video stream depends on the dynamics of camera movements and scene complexity, thus it varies greatly and a mechanism for controlling the video data rate had to be implemented. The amount of compressed video data is averaged over 1 second, using both key and differential video frames in the calculations. Under default settings, when the average data rate exceeds 25kB/s, the number of coded frames per second is decremented, otherwise it is incremented. In consequence, the resultant video stream is squeezed into fewer than 25kB/s, always at the highest possible frame rate. The compressed video is sent to the operator in UDP packets.

The snapshot option is initiated by the operator through a small TCP/IP packet. This is not depicted in Figure 2 for the sake of simplicity. A picture is captured from the camera and undergoes lossless JPEG compression. It is relayed to the operator by TCP/IP packets and displayed. The delay is not an issue in this case.

The GPS receiver returns coordinates (longitude and latitude) once every second. This data is then transmitted by UDP packets. Longitude and latitude are converted into the Cartesian coordinate system and the blind person's position is plotted on the digital map in the operator's computer. A screenshot of the operator's application is seen in Figure 3.

Figure 3. *Screenshot of the operator's application: A) The video stream, B) Digital map with GPS readouts, with small markers every 5 seconds, C) Connection controls and parameters.*

2.3 Anti-congestion Measures

The GSM connection is subject to the problems of congestion and poor link quality stemming from unfavorable locations (radio related phenomena, buildings, weather). This entails limited throughput and transmission lags. In order to detect and correct this problem, a special mechanism is implemented. At short intervals, default every 2 seconds, a time-stamped UDP packet is sent from the blind user's computer to the operator, where it is sent back. The packet roundtrip time and loss ratio are measured. These parameters reflect the network's condition. In the event of a compromised connection quality, the video frame rate is reduced to one frame per second. If the problem persists, the audio and video streams are put on hold to avoid further worsening of the situation. As soon as the connection improves, the audio stream is resumed. The video stream starts from a low frame rate (1 per second) and is slowly increased by the mechanism balancing the video bandwidth described previously.

A poor link is signalized to the blind person by special sound cues. This is to prepare the blind person to be more vigilant as the operator might answer with much greater delay or even be disconnected. When a disconnection occurs, the blind user hears a special alarm and can try to reestablish the connection by pressing a large button on the touch-screen.

The operator has the ability to manually suspend and resume the video stream to spare the bandwidth when video is not needed, for example during a lengthy conversation, or to avoid congestion when the signal strength is very poor.

3. FIELD TRIALS

The goals of the trials were to confirm the prototype's usefulness in real world navigation, reveal possible problems with outdoor use and determine future directions for development. The main problem with objective verification of outdoor path navigation is the fact that the efficiency and safety of a blind person traveling pre-defined paths is mainly dependant on the experience the person has with the route. This can be avoided by randomizing a selection of artificial paths as it was done in our previous experiment (Bujacz et al, 2008); however, this introduces a new problem. With random paths, the effectiveness of navigation chiefly depends on the orientation and mobility (O&M) skills of the blind person. To get rid of both these problems, we decided to observe the learning curve of navigation for multiple repeated runs of a path.

3.1 Trial Description

Three blind volunteers participated – all male, aged 25-45, two blind since birth, and one for the last 17 years. One of the participants retained marginal light sensitivity, which was however not useful for mobility. Every participant was taught to navigate two paths (approx. 150m and 190m long) on the university campus. Each was then asked to repeatedly transverse these paths, alternating navigation by a remote assistance and independently. The attempts were recorded, and the number of missteps and accidental collisions counted.

The paths on the university campus were chosen to provide multiple obstacles, such as stairs, trash cans, park benches, lamp posts and fire hydrants. Every blind volunteer used his long cane during the tests. The paths had only limited turns to be easily remembered. One of the experimenters accompanied the blind volunteers at all times, should an unexpected or dangerous situation arise.

Each path was completed in three different "modes":

a) *walk with a human guide* – the first walk on each path was in the company of a human guide, who explained the turns in the path and any dangers along it. All three participants claimed that one run was sufficient to learn each simple path, and most of the obstacles on it.
b) *remote guidance* – the blind participant wore the earpiece, chest-camera and the Flybook. The operator provided remote guidance on the base of the real-time video transmission and observed the volunteer's positions thanks to GPS readouts displayed on his digital map.
c) *independent walk* – the participants relied only on themselves to navigate the paths, they were warned when in danger or when they lost their way

3.2 Data Collection

During each path attempt the volunteer was closely followed by a sighted observer who took notes on the following occurrences during each path navigation attempt:

- *time* – Each path lead from a building door to another and back. The time was measured from the moment the volunteer let go of the doorknob, to the time until he touched it again after reaching the destination door.
- *missteps* – These were noted every time the blind participant slightly stumbled (without falling) or stepped onto the grass.
- *minor collisions* – These were noted when the blind volunteer collided with an obstacle, but only with his white cane, thus not endangering himself. This was usually occurring when the participant hit thrash cans or park benches slightly off the path, on the grass.
- *major collisions* – These were mostly avoided at the last moment thanks to warnings or support from the sighted observer. They were noted when the participant was about to collide with an obstacle with his body or has tripped hard enough to almost fall. The most frequently collided with obstacles were columns near the building entrances and short posts from a chain along the path.

The collected data is presented in Table 1 and the total results, summed for the three participants, on all repeated attempts are shown in Figure 4.

The GPS position readouts were recorded once every second. The experiments were recorded and later replayed so that the participants' positions at 5 second intervals could be plotted.

At the end of the experiment, all participants provided feedback about the proposed system, their experiences from the trials, and expectations from the developed device.

Table 1. *Trial data summary for the three blind volunteers.*

Path I		Time			Missteps			Minor Collisions			Major Collisions			Lost Way		
		JM	MM	RP	JM	MM	RP	JM	MM	RP	JM	MM	RP	JM	MM	RP
Assisted	1	03:27	03:58	04:06	2	1	2	-	1	1	-	1	-	-	-	-
Independant	2	03:31	04:00	03:50	2	2	2	-	2	2	-	1	1	-	1	2
Assisted	3	02:57	03:44	03:18	-	3	1	-	2	1	-	-	-	-	-	-
Independant	4	03:06	03:20	03:53	-	1	2	-	3	-	-	-	1	-	-	1
Assisted	5	02:58	03:06	02:55	-	3	1	-	1	1	-	-	-	-	-	-
Independant	6	03:05	03:30	03:10	-	3	1	-	-	-	-	-	-	-	1	-
Assisted	7	02:55	03:08	02:55	-	-	1	-	-	-	-	-	-	-	-	-
Independant	8	03:00	03:08	03:03	-	3	2	-	1	2	-	1	2	-	-	-

Path II		Time			Missteps			Minor Collisions			Major Collisions			Lost Way		
		JM	MM	RP	JM	MM	RP	JM	MM	RP	JM	MM	RP	JM	MM	RP
Assisted	1	03:21	06:00	04:00	-	3	-	-	4	-	-	-	-	-	-	-
Independant	2	04:02	06:41	04:40	2	1	1	-	3	2	-	1	2	-	2	2
Assisted	3	03:06	05:09	03:50	-	1	-	-	1	1	-	1	-	-	-	-
Independant	4	03:50	05:15	04:09	2	1	3	-	5	1	-	1	-	-	1	1
Assisted	5	03:58	03:58	03:37	-	2	-	-	1	-	-	-	-	-	-	-
Independant	6	03:17	04:41	03:51	-	3	1	1	4	-	1	2	1	-	-	-
Assisted	7	03:40	03:20	03:26	-	-	-	-	2	-	-	-	-	-	-	-
Independant	8	03:20	04:32	03:29	-	4	2	-	2	-	-	1	-	-	1	-

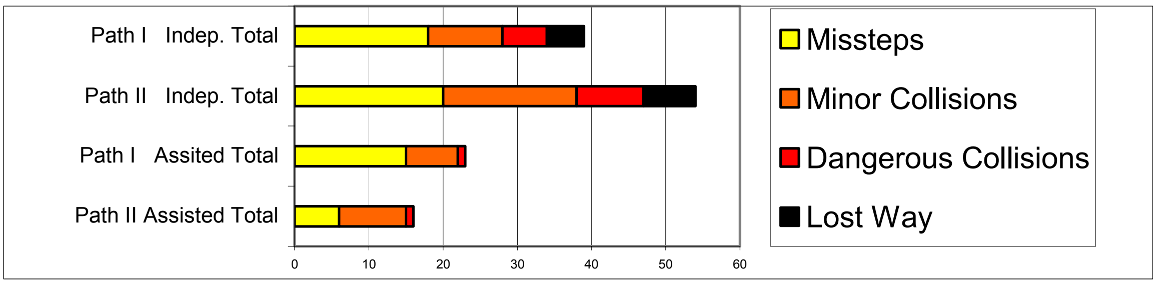

Figure 4. *The comparison of the total number of unfortunate event occurrences for assisted vs. independent trials totaled for all participants on all attempts.*

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4. DISCUSSION AND FUTURE WORK

Comparing the performance between the three participants listed in Table 1 clearly shows their strongly differing O&M skills. The oldest participant – JM, most experienced in independent travel, had almost no collisions and never lost his way. The two younger participants had considerably slower times and more accidents. Despite these big differences in skill, it is clear that the use of the remote assistance resulted in a significant reduction of missteps and collisions for all participants as seen in Figure 4. None of the subjects lost their way when assisted and there were only two potentially dangerous collisions noted, both for the same participant who blamed them on his overconfidence.

The increase in travel speed when assisted, which in the previous indoor trials reached 50%, was not as significant in the outdoor attempts, only 15-20%. This is primarily due to the real-world environment in which the trial participants were experienced in navigating. The trials were constructed in such a way as to quickly familiarize the blind volunteers with the paths, leading them to reach quickly a similar safe top speed.

4.1 Participants' and Operator's Conclusions

The operator's adjustment to each blind user's needs seemed to be a key parameter in providing effective navigation. When encountering obstacles, short and simple commands e.g. "park bench on your left, a doorway on half right" were far more welcome to most users than precise maneuvering instructions. To ensure the blind persons maintain a proper walking direction it was advisable to find a travel boundary e.g. „walk along the left curb''. From the psychological point of view operator-user communication should be settled individually with every blind user. Some participants only wanted short navigating instructions and obstacle warnings; others felt more comfortable and safe after a more detailed description of the environment. The trial participants all proposed of their own accord that even if an operator service was never put into life, the constructed device would be of great help if the connection could be established with family members at home.

4.2 Improving GPS Navigation

One of the problems encountered during the outdoor trials was that in the presence of high buildings GPS readouts could err by over 30 meters. This can be seen on Figure 3, where the route constructed out of the GPS readouts seems to indicate the blind participant walked onto the parking lot, while in reality he stayed on the path. The workaround for this problem is to combine the data from the GPS receiver with data from additional sensors – accelerometers, gyroscopes and/or a digital compass.

4.3 Target Platform

The solution used in the prototype consisting of an ultra-mobile notebook PC and a modified webcam is a plausible, but probably an overly large and expensive target platform. Interviews with the blind volunteers concluded that the price, size and appearance of any electronic aid is of great importance to them. The target device must be small enough to fit in a pocket or a light shoulder bag. It cannot be overly exposed and too expensive, as all three trial participants have been victims of cell-phone theft.

The target platform remains undetermined and will depend on further trials with mobile phones and microcontrollers. A likely solution might be using a mobile phone to maintain the user-operator connection, while an external microcontroller circuit handles the more resource consuming tasks of voice and video compression.

5. SUMMARY AND CONCLUSIONS

The results of outdoor trials of a prototype tele-assistance system for the blind are presented in the paper. The system consists of an ultra portable Flybook laptop with a built-in HSDPA modem, a GPS sensor, a wide-angle camera and an earpiece. A software package for streaming video, audio and GPS readouts over the GSM channel has been developed and proven efficient and reliable.

The results from trials with participation of blind volunteers showed improved travel speeds and greatly increased safety when compared to unaided travel. The trials were conducted in a way to observe the changes in blind participants' mobility with growing familiarization with a route, both when navigating independently and with remote assistance. When utilizing the help of the remote guide the blind persons traveled 15-20% faster, did not lose their way, almost never endangered themselves with major collisions and approximately halved the number of missteps and minor collision. Work on the system will continue with the aim of development of a commercial application.

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Accessible virtual environments for people who are blind – creating an intelligent virtual cane using the Nintendo Wii controller

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ABSTRACT

People who are blind tend to adopt sequential, route-based strategies for moving around the world (Golledge et al, 1996). Common strategies take the self as the main frame of reference, but those who perform better in navigational tasks use more spatial, map-based strategies (Hill et al, 1993). Training in such strategies can improve performance (Cummins and Rieser, 2008; Simonnet et al, 2006). Virtual Environments have great potential, both for allowing people who are blind to explore new spaces, reducing their reliance on guides, and aiding development of more efficient spatial maps and strategies. Importantly, Lahav and Mioduser (2005, 2008) have demonstrated that, when exploring virtual spaces, people who are blind use more and different strategies than when exploring real physical spaces, and develop relatively accurate spatial representations of them. The present paper describes the design, development and evaluation of a system in which a virtual environment may be explored by people who are blind using Nintendo Wii devices, with auditory and haptic feedback. Using this technology has many advantages, not least of which are that it is mainstream, readily available and cheap. The utility of the system for exploration and navigation is demonstrated. Results strongly suggest that it allows and supports the development of spatial maps and strategies. Intelligent support is discussed.

1. INTRODUCTION

The Terraformers game is playable by players who are blind, who can play the game against sighted opponents (Westin, 2004). Terraformers offers auditory navigation and game information, which blind players can use successfully to navigate its virtual environment and to play the game. Enabling users who are blind to operate in virtual environments (VEs) has many potential benefits. Skills such as navigating around the real world, traveling, and crossing the road are major challenges for the blind. Applications of VEs have been developed for training in basic skills, travel training and for learning to cross the road, for people with learning difficulties (Brown et al, 2005). Such applications would be of great benefit for people who are blind. In order for a blind person to be able to find their way around a new environment, they need first to be taken around that environment by a guide. While doing so they establish points of reference in that environment. In the case of those with a guide dog, these points of reference represent locations to which they can instruct the dog to go. People who are blind may have to be always accompanied in environments which are complex and/or not encountered frequently. Being able to practice navigating around environments, and to practice traveling and other skills in safe VEs would be helpful for building up knowledge, experience and confidence. Improving the accessibility of VEs could have many possible benefits.

People who are blind tend to adopt sequential, route-based strategies for moving around the real world; common strategies take the self (or body) as the main frame of reference, as opposed to an external frame of reference (e.g., see Golledge et al, 1996). There is a great deal of variability in the navigational strategies used by people who are blind, with those who perform better in navigational tasks being those who use more map-based strategies (Hill et al, 1993). Training in such strategies can greatly improve performance (Cummins and Rieser, 2008; Simonnet et al, 2006). Simonnet et al (2006) have detailed documented strategies and distinguish between egocentric frames of reference, where objects and locations are related to a person's particular perspective, and exocentric frames of reference, where external frames of reference are

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used. External frames of reference and map based-strategies allow more efficient representation which enables flexibility, so that alternative routes can be taken, shortcuts can be made and destinations changed, because they encompass a more complete representation of the environment to enable navigation from a number of perspectives (Golledge et al, 1996). The actual mobility training people who are blind receive is generally basic and egocentric (see section 6.2 below).

VEs have great potential for supporting and facilitating the construction of exocentric cognitive maps by those who are blind. The visual modality lends itself to global spatial representations. These are more difficult to derive from haptic sources, which are by their nature more local and sequential. This property of haptic information, combined with the fear of collisions, encourages the use of egocentric frames of reference by people who are blind. However, functional equivalence of haptic and other non-visual information to visual information can, under the right conditions, be indicated and the possibility that they may all contribute to admodal spatial representations exists (Loomis and Klatzky, 2008). Cognitive maps can be created by the blind; it has already been noted that the more successful navigators tend to use more map based strategies. Lahav and Mioduser (2005, 2008) demonstrated that interacting with a haptic virtual environment can facilitate the construction of mental maps of spaces and thereby contribute to blind people's spatial performance. They found that, when an experimental group of people who are blind explored a haptic virtual environment, they developed new strategies, and applied existing strategies for navigation in different ways, compared to a control group, who explored the real physical environment. When questioned about the environment, the experimental group had better structural descriptions of it and the location of objects within it. Further, when the experimental group went on to explore the real environment, they were more successful in completing target and perspective oriented tasks, and completed them more quickly using more direct routes than the control group. These results strongly suggest that the experimental group had developed cognitive maps with properties much more like those of sighted navigators. That is, exploring the VE and experiencing the associated feedback appeared to enable the development of a more complex, wholistic, exocentric cognitive map of the environment.

The use of VEs for exploration and navigation is not only beneficial for building up knowledge, experience and confidence, but also facilitates the development of spatial models and strategies. People interact with Lahav and Mioduser's VE via a force feedback joystick, and receive several types of auditory feedback. The present research has investigated the use of the Nintendo Wii remote controller (Wiimote) as an adaptive assistive device, and in this case as a device for people who are blind to use for interacting with virtual environments. The Wiimote allows the user to interact with a system via movement and pointing. In addition, visual, auditory and haptic feedback is available. Using the Wiimote has many advantages, not least that it is mainstream, easily available and relatively cheap.

2. THE WIIMOTE AS AN ASSISTIVE DEVICE

The Wii has been investigated as a platform for the development of assistive technology, by interfacing the Wiimote with a personal computer, and by detailing the technologies involved (e.g., Battersby, 2008).

2.1 Interfacing a Wiimote with a PC

Using the Wiimote's Bluetooth capability it proved to be a simple task to interface the Wiimote with a standard PC. The Windows Wii application (WWii) was created to handle connection and pairing between the Wiimote and the target operating system. Following on from earlier iterations (see Battersby, 2008), WWii has been used to facilitate further research and development. WWii is a functional windows-based driver application written in C# with Peek's (2008) Managed Library for Nintendo's Wii remote (Wiimote) as its heart. It provides facilities for keyboard, mouse and joystick mapping, for peripheral input data capture and a basic capacity for the replay and analysis of any captured data. WWii not only provides the facility for the Wiimote to be mapped to the windows system but also supports multiple extensions such as the Wii Classic Controller, the Wii Nunchuck and the Wii Fit board. Interface panels have been created to support mapping functionality by enabling a user to configure each of the Wiimote's physical inputs to any desired keyboard or mouse input combination (see figure 1). In effect this enables the Wiimote to be seen by the system as any of the highlighted devices, limited only by the volume of inputs available from the device. Customizable feedback is developed through the feedback mapping panel, where flags may be set to operate any of the Wiimote's feedback mechanisms.

2.2 Wiimote Sensor Technology

2.2.1 The Accelerometer. The accelerometer contains a micro mechanical structure supported by silicon springs. It measures linear accelerations along three fixed axes; it is unable to distinguish between linear motions and rotations, and so it is capable of measuring only pitch and roll angles.

2.2.2 The Optical Sensor. The optical sensor is an infrared camera situated at the front end of the Wiimote. The camera is connected to an integrated image analysis chip that can identify up to four individual Infrared light sources and report their position, approximate size and level of intensity. The light sources for the present application are provided in the form of two clusters of infrared LEDs situated at two opposite ends of a stationary bar, which was a modification of an existing USB/battery powered product. The image sensor sees the light as two bright dots separated by a known distance. Triangulation is used to calculate the distance between the bar and the Wiimote. The camera projects a 1024x768 plane front of the user and positional/rotational data is obtained in reference to this plane. This is possible as the position of the sensor bar and distance between the LED clusters remains constant. This system allows the Wiimote to function as an accurate pointing device and provides the yaw value, so that the Wiimote can be tracked in 3D space.

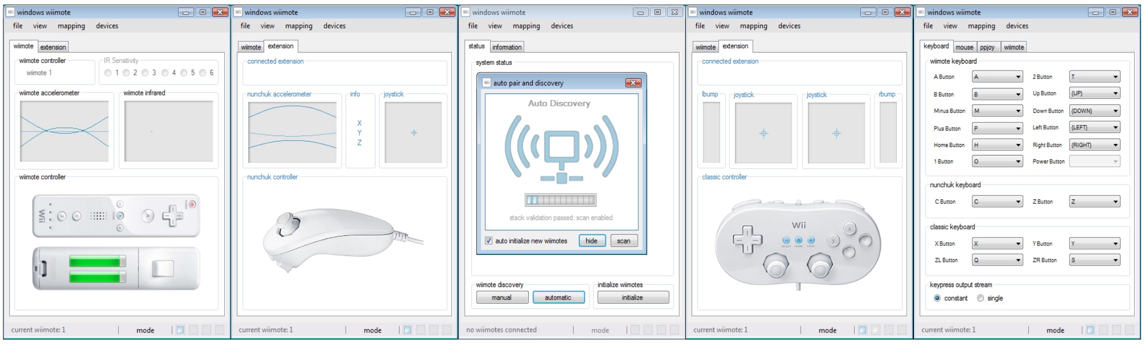

Figure 1. *Part of the Windows Wii driver application interface.*

2.3 Practical Investigations of Wiimote Sensors

In order to test the interface functionality of the two Wiimote sensors a simple test environment was created that consisted of a virtual representation of the Wiimote within 3D space. The environment was constructed within AutoDesk's 3D Studio Max application and interactive capability was provided by importing the environment into Adobe Director, where navigation and response to system input could then be coded. Successful performance was demonstrated by slaving the motion of the virtual Wiimote to that of a real world counterpart. The initial testing of the Wiimote sensors highlights the Wiimote and its technologies as more than adequate for the development of assistive concepts and solutions. Used in conjunction they provide required 6 degrees of freedom needed to orientate a body within 3D space. The Wiimote can be used as a 2D pointing device via the optical sensor and can easily provide 2D mouse-like interaction.

2.4 Feedback functionality of the Wiimote

In addition to providing system input the Wiimote is capable of providing basic auditory, visual and haptic feedback. The speaker on the Wiimote allows audio content to be transmitted from the host to be played back. By default the Wiimote indicates its player assignment by lighting the corresponding LED. The LEDs are also used to indicate the power level of the Wiimote's battery upon power up. This visual feedback is redundant for the present application. The Wiimote also includes a rumble device which can be set to either an on or off state. Manipulation of the frequency of operation can be used to provide pulses to create the illusion of differing strengths of rumble. This device offers great potential for haptic feedback.

2.5 Expansion capabilities of the Wiimote

The Wiimote features an expansion port. This provides the facility for the connection of additional auxiliary controllers to augment the input capabilities of the Wiimote. The Wiimote's assistive capabilities can also be expanded via implementation of software solutions.

All the functional attachments use the Bluetooth interface of the Wiimote to communicate with the Wii console, thus allowing them to be much simpler and cheaper to implement than the Wiimote itself. Attachments can be added and removed from the Wiimote whilst in use without resulting in device damage. The main attachment to date for the Wiimote is the Nunchuk controller. The primary component of the Nunchuk is an analogue thumbstick, which outputs 2D axis data. In addition to the thumbstick the Nunchuk has two buttons labeled as C and Z and a three-axis accelerometer sensor.

3. THE WIIMOTE AS A CANE WITHIN 3D ENVIRONMENTS

The Wiimote's ability to describe a body within 3D space means that it can be used rather like a cane, and therefore provide an interface to 3D environments for the visually impaired. The virtual Wiimote counterpart uses distance measurements obtained by ray casting to control feedback in the form of vibration and auditory signals.

3.1. Design

In order to investigate the potential of the Wiimote as a virtual cane a test environment was created. Additional functionality was added to the WWii enabling it to host Shockwave environments thus providing direct communication between the environment and the Wiimote. Other environments could easily be loaded into the application.

Iterative design and evaluation of the Wii cane system was carried out by a software engineer and a Computing Masters degree student who is blind (subject A) in line with user-centred design methodology (e.g., Lannen et al, 2002; Battersby et al, 2004). Early design iterations highlighted the need for initial orientation and calibration. A number of variables needed to be explored, including the relationship between the motion of the Wiimote and its motion relative to the environment, and the type and nature of the different types of feedback and their relationship to the environment and the objects in it. A number of alternative configurations were explored, leading to a design suitable for testing and evaluation. For all configurations, the Wiimote is used to scan the environment in front of the user; the whole plane can be scanned, that is left-right, up-down, or any other angle. Speed of motion in the VE was set at the speed identified as comfortable from extensive experience of user testing in Serious Games; strides were set at about a metre for the same reason (e.g., Brown et al, 2007).

Configuration 1:

The Nunchuck was used. The thumbstick could be used to direct motion in eight directions at each 45 degree point. The Nunchuck was used to determine direction with respect to self. That is, whatever direction the thumbstick was held in, when the Z button was pressed motion would be in that direction. The aim was to provide an on the spot point of self-reference. As with a person turning, the thumbstick would be turned and motion would proceed in that direction when the button was pressed. Rumble varied according to distance from an object, with constant rumble on collision. Pressing a button produced spoken distance and object name. However, there is no external frame of reference with respect to the environment, and the user was disoriented.

Configuration 2:

For configuration 2 the Nunchuck was removed because the added complexity appeared to outweigh any benefits. Configuration 1 needed additional environmental cues in order to orient the user within the space. Some available possible cues are footsteps, rumble on approach (pulsing could indicate distance), rumble on collision (constant), sonar and auditory signposts. The feedback used was rumble (constant) on collision, and sonar, whereby frequency of beeps indicated distance. As with the previous configurations, pressing a button produced spoken distance and object name. In addition, on entering a space, a description of the space is available via a button press. In order to turn, the Wiimote was rolled to the left or the right. A beep indicated turning mode, and every beep indicated a 10 degree turn. The left and right beeps were different to make them discriminable. Motion was provided by a button press on the Wiimote, inducing motion in the last facing direction. Because of the positions of the various buttons on the Wiimote, it proved difficult to control; additionally, button presses tended to move the Wiimote, producing positional confusion. The Nunchuck was therefore re-introduced in configuration 3.

Configuration 3:

In this final configuration, left and right turning was achieved by rolling the Nunchuk to the left and to the right, producing a 10 degree turn. Left and right step sounds provided turning feedback, which proved easy to interpret. Motion forwards and backwards was initiated by tilting the Nunchuk up or down. The Wiimote was used for scanning the space. Beeps were used for indicating different types of objects and their distance. Different tones of beep were used to indicate furniture, walls, doors, floors and out of scanning plane (accompanied by a constant rumble). The rate of the beeps increased as any object was approached. There was a constant rumble on collision. Subjects were told when they had passed from one space to another (for the last subject this was implemented as a whooshing sound on transition). As with the previous configurations, pressing a button produced spoken distance and object name.

This configuration separated motion (controlled by one hand with the Nunchuk) and scanning (controlled by the other hand with the Wiimote), and this is a clearer arrangement. The design now appeared to contain the necessary information for successful navigation, and was stable enough for evaluation.

3.2 Evaluation

3.2.1 Test environment. Having arrived at the system design of configuration 3, another VE was created for testing the system. This VE is a representation of part of the third floor of the Nottingham Trent University Computing and Informatics building (see Figure 2 for floor plan). This was chosen for a number of reasons:

i) It is easily available.

ii) It is a real functional space.

iii) It contains an open plan area with a number of obstacles of different types within it. Consequently it contains numerous potential areas for navigation and numerous potential navigation and perspective tasks.

iv) It is irregular, the level of complexity encouraging development of spatial awareness and navigational skill.

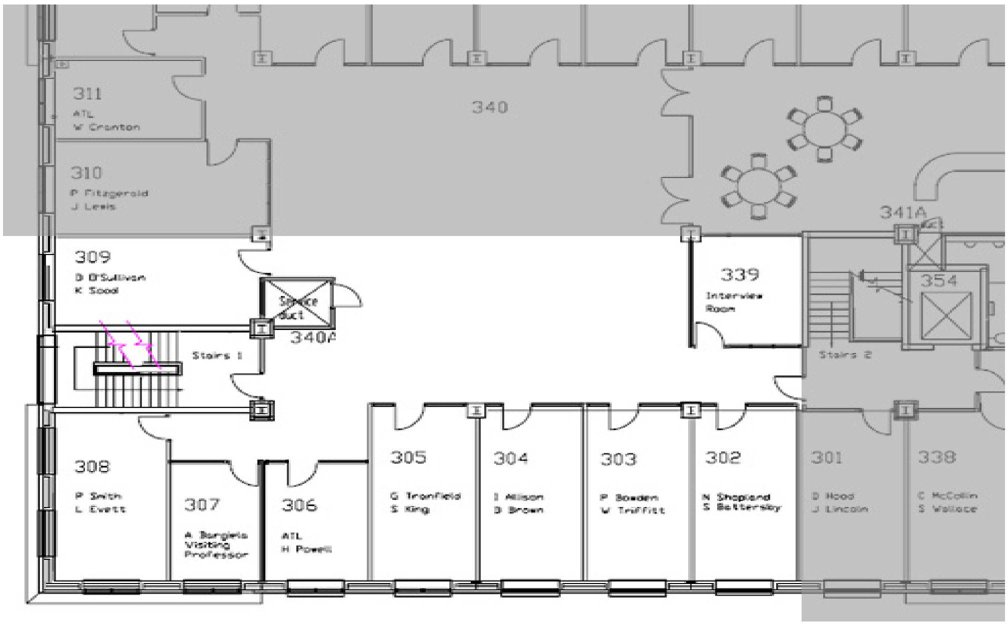

Figure 2. *Floor plan – only the shaded section was used for navigation in the present evaluation.*

3.2.2 Subjects.

Subject A:

Subject A is 52. He is the person involved with the design of the system. He has no functional vision. He can under some circumstances detect light, although this has to be very bright. His eyes were not formed properly at birth. He has Hallerman-Streiffe syndrome. He was blind until about the age of 2, when he had surgery to restore his sight. After the surgery he had functional sight; his distance vision was fine but close up he could not read without a lens, or recognise faces. He could move around and navigate without major difficulty. His sight began to deteriorate in his late 30s until the age of 42, when he had no useful remaining vision. He received basic training in the use of the cane around this time. This involved holding the cane and sweeping and turning, identifying landmarks, and the use of inner and outer shorelines. There was some discussion of using smells and sounds. There was some learning of routes. The training focused on egocentric and route strategies. Beyond this people develop their own strategies, and all three subjects reported doing so. Independent traveling in new spaces is very difficult; in such cases, a trainer will guide the person in at least the first instance. This is also true when dogs are used. The trainer will come out to help the person and the dog identify reference points for future use. Subject A has been guided by dogs for some years. Training with a dog is intense, starting with three weeks solid at a centre or at home. Routes are learnt by walking the route with the trainer, and identifying reference points to tell the dog to go to. Subject A is currently with his fourth dog, and so is experienced at being part of a dog/person team. He commonly travels alone with the dog and is a frequent user of public transport.

Of the three people who took part in this evaluation, subject A is the most familiar with the space being used. While he often visits certain parts of it, other parts he knows very little, if at all.

Subject E:

Subject E is 27 and is partially sighted, although could be registered blind if she requested it. Currently she has minimal vision in her left eye, which is only apparent when her right eye is shut or obscured. In the right eye she has tunnel vision, with a section missing on the nasal side, and blind spots. She was very short sighted, with some retinal damage, up until 9 years ago when she suffered several bouts of optic neuritis. Her vision is currently stable but likely to get worse. She received basic cane training, similar to that of subject A, when her vision first deteriorated. She is familiar with a very limited part of the area being used in this study.

Subject H:

Subject H is 38, and was very short sighted up until the age of 17, when he was registered blind. His sight had been deteriorating from the age of about 10. He suffers from retinitis pigmentosa. When registered blind he received basic cane training. He has had a guide dog for the last three years. At work he has a full time support worker and so is often guided. Subject H has not visited the evaluation area before.

3.2.3 Testing. At the start of each session, subjects were asked their age, their sight history, the mobility training they had received, and how they generally got about. Subjects were then taken into room 302, which was designated the training room in the VE. Subject A had been in this room often, and in the room 339 opposite. Both he and subject E were aware of the short corridor leading from the door from the stairs to the rest of the space. Subject A has visited two other offices down the side of the space, and had sat on one of the sofas. This was the limit of his knowledge. Subject E had been guided to an office at the end of the line of offices on two or three occasions, and this was the limit of her knowledge. Subject H had the short entrance corridor described to him for orientation. Figure 4 shows views of the space.

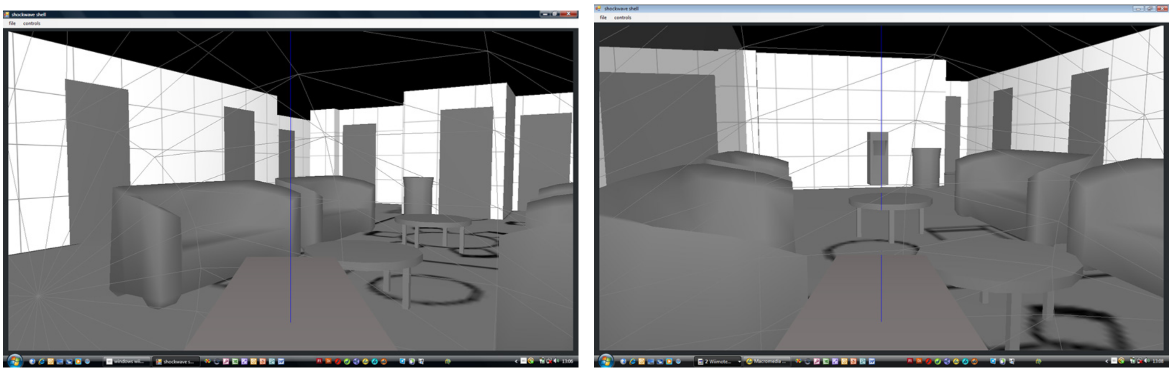

Figure 3: *A view of the space from either end*

Each subject was told that they were to use the Wii controls to explore a virtual representation of the open area, which contained some items of furniture and other items, and was edged by numbered offices and other doors. They were instructed in the use of the controls and the feedback they should expect, which were also demonstrated. They were given feedback on their use of the controls. They were asked to explore room 302 to get used to the controls and to ask any questions. The height of the infra red bar was adjusted to suit their comfortable holding of the controls. Once they seemed familiar with the controls they were asked to find the door and exit 302 (this was the only door they could pass through), and then to explore the open space for as long as they liked. During their exploration, further feedback on their use of the controls was given, and, in the case of subjects E and H, they were given tasks to complete (e.g., “there are some tables, try and find them”) to ensure they had explored all of the space. Once they had explored the space to their satisfaction they were asked to return to room 302. They were then asked to describe the space. The subjects were then asked to go out into the real space with their canes. Subjects A and E were told there was an object on table 2 and were asked to find it and take it to the fire door. Subject H was not very successful in exploring the virtual space so he was taken to the top of the open space, asked to find the tables and from there the fire door.

All subjects were then asked some questions about the ease of use of the system and their views of it.

3.2.4 Results. Both subjects A and E managed to explore the whole of the space, find all the objects in it and most of the doors. When asked to describe the space they gave a fairly accurate description of it, its shape and the positions of the objects in it. When asked to find the object and take it to the fire door, they both did so directly and with confidence. They found the controls a bit challenging but also talked about the space in spatial terms and thought it would be a good way for people who are blind to learn to navigate new spaces. Subject E, when asked to find the tables in the VE said "let me picture it", thought about it and then found them.

Subject H struggled to explore the space. Although he seemed to understand the controls and the feedback, he often went out of plane and collided with objects. In these cases he made little attempt to either get back in plane or out of collision. After a short while he was reminded what the feedback was telling him and what to do about it. He did manage to visit most of the space, but mainly by luck and prompting rather than by making a systematic effort to do so. He could not describe the space apart from saying he knew there was a space, he had no idea of the shape, he knew there were sofas, tables and bins but not where they were. He was not asked to find the object but taken into the space and asked where the tables were, which he found quite easily, and from there to go to the fire door. He went to it almost directly. While he had found the exploration difficult and did not seem to have much idea of the space, he did not have any trouble finding objects in the real space. His residual vision helped him find the tables, because the tables are light coloured and under a skylight, but this would not have helped him find the fire door from the tables.

Subjects A and E had some difficulty turning. Often they did not roll the Nunchuk far enough to effect a turn, and they over-rolled it when returning to centre. However, they both liked the correspondence between the movement of the device and movement effected in the VE. Subject E had the same problem, and reported the controls as difficult. He was reluctant to move the Wiimote at all.

4. CONCLUSIONS

Overall, the results of the evaluation were positive. Subjects A and E enjoyed using the system, appeared to develop clear spatial maps of the space, and were able to successfully navigate in a space which was largely new to them. Subject H was not so successful, but did seem to have some idea of layout. Subjects A and E both use computers regularly. Subject H does use computers but described himself as a technophobe. He is often guided. Subject A often travels independently. Subject E is generally independent. Subject A is obviously familiar with the controls. Subjects E and H had both used the Wii game system previously. Subjects A and E were tested first and picked up the controls very quickly. Both these people are frequent and confident computer users. It is often noted in the literature that there is a wide range of strategies and navigational abilities used in spatial tasks amongst people who are blind (e.g., Hill et al, 1993). It was clear from the evaluation that training for subject H needed to be taken more slowly, and this may well be the case for other people. Use of the thumbstick may be easier than rolling the Nunchuk, and this will be an available option in future designs. The results support the idea that the system can be used to develop and support cognitive spatial maps and strategies. Further testing is planned to establish this point more rigourously. Incorporation of the Wii Fit board into the system would provide additional kinaesthetic and proprioceptive feedback. It is currently integrated into the WWii application, but investigation is required to integrate it into the navigational system.

The use of the Wii devices allows a greater range of navigational information than the force feedback joystick used by Lahav and Mioduser (2005, 2008). The Wiimote can be used to scan around the environment to explore and to decide where to direct motion.

Other aids to navigation are to be developed in future systems. Presently, on transition to a new space, a description of the space is available via a button press. It is planned to make this option available at any time. Incorporation of auditory signposts and intelligent tutors into the system are planned. At present, the name of an object at which the Wiimote is pointing is available with a button press. Additional information could be incorporated at this point. Auditory signposts at appropriate places, such as by doors to new spaces, that explain where the door leads and how to navigate within the new area would be useful. Virtual tutors could provide additional information. Virtual tutors could appear at points where the traveler gets stuck to advise on how to make progress. An intelligent agent, which gives context-dependant spoken warnings and advice is being designed to support the virtual cane. This will enhance navigation and will provide additional functionality. Systems such as the present one will facilitate the development of accessible Serious Games.

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Mobile audio assistance in bus transportation for the blind

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ABSTRACT

People with visual disabilities have serious difficulties when mobilizing through the city on the public transportation system. We introduce *AudioTransantiago*, a handheld application that allows users to plan trips and provide contextual information during the journey through the use of synthesized voices. The usability and cognitive evaluation of *AudioTransantiago* was performed using a prototype evaluation in order to identify and solve usability issues, ending up with an intuitive and simple interface. Finally, a cognitive impact evaluation administered during bus trips taken with the assistance of *AudioTransantiago* demonstrated that the software provides more autonomy and effectiveness for users' trips, improving their orientation and mobility.

1. INTRODUCTION

It is widely recognized that visually handicapped people have difficulties moving around independently (Petrie et al., 1997; Engelbrektsson, 2004; Gill, 2005). Orienting oneself and moving around quickly, efficiently and independently within a space is a difficult task that depends on a series of highly complex cognitive processes, including perception, codification, learning and memorization of spatial information (Espinosa et al., 1998). In particular, people with visual disabilities have problems traveling independently by way of public transportation (Baudoin et al., 2005; Engelbrektsson, 2004; Gill, 2005; Sánchez and Maureira, 2007; Sánchez and Sáenz, 2006), starting with the difficult access to the information necessary to plan their trips (Petrie et al., 1997; Engelbrektsson, 2004; Sánchez and Maureira, 2007; Sánchez and Sáenz, 2006, Koruda et al., 2002). In addition, the scarcity of contextual information about the trip makes their orientation difficult and makes it impossible for them to identify their position on the route with certainty and to make safe decisions when presented with some kind of difficulty (Kulyukin et al., 2004; Vogel, 2003).

There are different trip planning systems for both pedestrians and those who use public transport (Gill, 2005; Sánchez and Maureira, 2007; Sánchez and Sáenz, 2006). As such, several authors suggest that through the use of software applications that provide contextual information about the different environments involved in the trip, the users are capable of constructing a mental model of spatial distribution that is adjusted to reality (Sánchez and Maureira, 2007). Moore (2002) presents a support system for blind user mobility in real spaces called Drishti. This system includes the use of wireless technology, voice recognition and synthesizer, geographical and global positioning systems and internet connection. Drishti provides contextual information and seeks to optimize the possible routes that blind users could take. This software application is thought of as a supplementary system to other support systems for orientation and mobility, such as guide dogs and white canes.

The diminished or lack of the visual channel as a source of information for users with visual impairments is compensated for with information obtained from other senses (Lahav and Mioduser, 2004). In particular, blind users use their sense of hearing as a main source of information and knowledge for learning purposes (Sánchez and Sáenz, 2006). It is for this reason that the majority of the aids for non-sighted people use auditory interfaces (Massof, 2003), with either a synthesized voice or non-verbal sounds. The positive effects that can be obtained from the use of such technologies include a considerable improvement in the users' quality of life, a reduction of stress, anxiety and uncertainty caused by taking trips, as well as a higher degree of independence (Marston and Golledge, 2000).

At the beginning of the year 2007 in Santiago de Chile a new system of urban transportation was implemented called *Transantiago* (The Economist, 2007). This system emerged out of the almost unmanageable and chaotic situation in transportation that had been operating in Santiago up until the end of

2006. The city's population had clearly expressed its discontent with the transportation system. In an acceptance survey for public systems taken in 2002, public transportation was graded with an average of 11.2 points on a scale of 1 to 100 (Cruz, 2002). Under the new *Transantiago* system, the city was divided into different zones (service units) that have different local bus routes (services) and that are connected by longer, more extensive services called *Troncales* (main bus routes). With the implementation of this system, it has been possible to model the services: each route has a series of stops assigned to it at which the different buses stop to pick up passengers (in addition to the stops at red lights). *Transantiago* does not offer a solution for people with visual disabilities to be able to utilize the bus transport system on a day-to-day basis. Faced with this situation, we propose *AudioTransantiago*, which emerges as an alternative for providing contextual information at each *Transantiago* bus stop through the use of a pocketPC, which allows a user with visual disabilities to plan his/her journey before taking it, taking into account the streets and important landmarks near each bus stop that he/she will utilize during the trip. It also allows the user to access this information during the trip and, in case of a detour or the suspension of a particular service, it offers the user alternative services to be able to complete the trip.

This study introduces AudioTransantiago, a handheld application that allows users to plan trips and which provides contextual information during the journey through the use of synthesized voices, as well as the usability and cognitive evaluations employed to tailor this application to the characteristics and needs of blind users and to determine the cognitive impact of AudioTransantiago on the user's orientation and mobility.

2. SOFTWARE

AudioTransantiago stores the contextual information on each stop of the *Transantiago* routes, from which the user chooses in order to plan his/her trips in advance. In addition, this software navigates the stops of a previously planned trip in order to strengthen orientation and facilitate the blind user's journey.

2.1 Logic Design

The software application is designed for pocketPC with Windows Mobile 2005 and .NET Compact Framework 1.0, using the programming language C#. The system also uses a Text-to-Speech engine (TTS) from the Acapela Group.

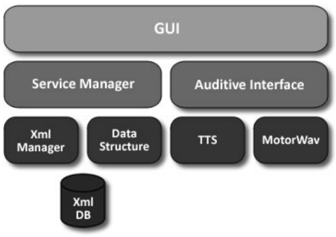


Figure 1. *Architecture of AudioTransantiago*

AudioTransantiago is designed modularly in order to facilitate the development and re-use of its components. In Figure 1 there are 3 identified layers of which the software is composed. The first consists of a superior layer (GUI or Graphical User Interface) that manages the interaction between the user and the interface. The second layer consists of the data administration (Service Manager) and the audio components (Audio Interface). The third layer is that which supports the management of the data and its representation (XML Manager, Data Structure, TTS, MotorWay and XML DB).

AudioTransantiago stores the contextual information for every bus stop on the *Transantiago* routes, which the user can select beforehand in order to plan his/her trips. In addition, it navigates the stops of a previously planned trip in order to strengthen the user's orientation and facilitate his/her journey. The data employed by *AudioTransantiago* is stored in an XML document, which includes the city's service units, the services or routes and their stops. In turn, the software incorporates additional information on the nearby streets around them, as well as significant landmarks near to the bus stops.

2.2 Interaction with the User

The design of the interface considers the results discovered in previous studies with blind users and audio-based interfaces. The most important aspects taken into consideration are the circular menus, the color contrasts and the use of sound mixed with a synthesized voice and non-verbal audio (Sánchez and Maureira, 2007; Sánchez, 2007).

AudioTransantiago presents a Text-To-Speech, audio-based interface through which it conveys information to the user, complemented by non-verbal sounds that help to identify the navigational flow within the application menus. This is improved upon with a minimalist graphic interface, which includes only the name of the selection that is being used and the option that has been selected, utilizing a strong color contrast (yellow letters over a blue background) that can be useful for those users with residual vision who can only distinguish shapes when displayed with highly contrasting colors (see Figure 2A).

(A) (B) (C)

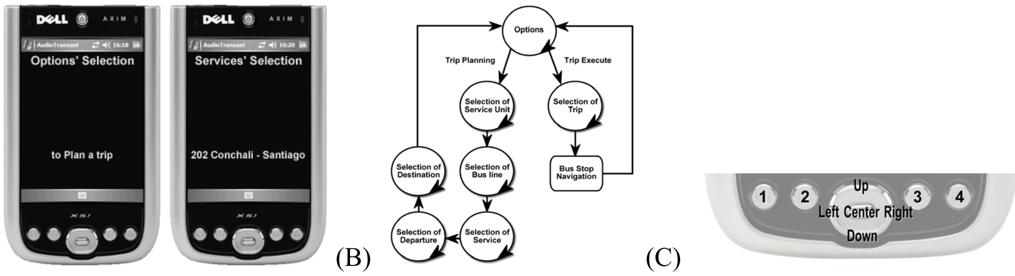


Figure 2. (A) *AudioTransantiago Interfaces* (B) *Navigational Flow of the AudioTransantiago menu* (C) *Denomination of the buttons on a pocketPC*

2.3 Navigation

Navigation through the software application's different functions is done through circular menus (Sánchez and Maureira, 2007), and through the use of the buttons below on the pocketPC (see Figure 2C). The advantage of these menus is that they facilitate the searches within the lists, which have a large number of different elements. The navigational flow through the software's menu structure is described in Figure 2B. The software application's two operational functions can be accessed through this structure (planning a trip and making a trip), as well as their respective submenus, which are explained in the next section.

A diagram with the denominations of the various buttons on the pocketPC can be observed in Figure 2C. In table 1, all the functions of the pocketPC buttons utilized by the software are specified.

Table 1. *Functions of the buttons used in AudioTransantiago.*

Button	Function
1	Indicates the current section in which the user is located
2	Repeats the last instruction given to the user
3	Indicates the current option
4	Indicates the additional contextual information on the stops when these are being reviewed to plan a trip, or during an actual trip
Up	Navigates the current options in the opposite order. While in the actual trip mode, this button provides alternative services to the service that is being used
Down	Navigates the current options. In the actual trip mode, this button advances to the following stop
Left	Returns to the previous menu
Right	Stops the reproduction of the current text
Center	Accepts the current option

2.4 Functions

AudioTransantiago has two main functions: planning a trip and making a trip. The first consists of planning a trip using a *Transantiago* bus, on what could be a frequent route or not. On the other hand, making a trip corresponds to carrying out a previously planned trip with the software application.

2.4.1 Trip Planning. In order to plan a trip the user must perform the following steps: 1. Select a service unit (area of the city where he/she will travel), 2. Choose the service or route that he/she wants to use, 3. Pick the direction in which he/she will travel, 4. Define a starting point at a specific stop, and 5. Define a destination stop. In following these steps, the user is able to create a trip that is stored in the pocketPC and which can be consulted by selecting the "Trip Execute" option.

2.4.2 Trip Execute. This option allows the user to make a previously planned trip. For the correct use of the information encapsulated in the previously planned trip, a *navigation in advance model* was proposed, in which the user can advance manually to the following stop before arriving. As such, he/she can consult the contextual information about the stop (streets and nearby points of interest), and get an impression about the stop's surroundings before getting there. In addition, the software application provides information about alternative routes to the one the user is using, and just in case there is some emergency or problem during the trip, it offers services that pass through the stop where the trip was suspended or detoured, and which directs the user to the destination stop defined in the originally planned trip.

3. EVALUATION

3.1 Usability Evaluation

3.1.1 Participants. The sample for the evaluation of the *AudioTransantiago* prototype was made up of 6 legally blind participants, between the ages of 27 and 50 years old, all residents of Santiago de Chile. Case 1 was 32 years old, male and totally blind (chronic uveitis), case 2 was 33 years old, male and totally blind (retinitis pigmentosa), case 3 was 34, male and with residual vision (miotic maculopathy), case 4 was 50, male and with residual vision (deform maculopathy), case 5 was 35, male and with residual vision (optic atrophy), and case 6 was 28 years old and totally blind (bilateral atrophy of the optic nerve). They participated in several activities, 3 of them had residual vision and all were men. Two special education teachers also participated, which are specialists in visual disabilities, and one engineer who is an expert in usability evaluation.

3.1.2 Instruments. The usability evaluation was done by means of a Software Usability Questionnaire (Sánchez, 2003), adapted for adult users in the context of this study. This questionnaire includes 18 closed questions about the specific aspects of the software's interface, together with 5 more general, open-ended questions relating to trust in the system, the way of using the system and the perceived sensation of utilizing these devices as a way of helping the users to travel on a bus system. The results obtained can be grouped into four categories: (1) Satisfaction, (2) Control and Use, (3) Sound, and (4) Image.

3.1.3 Procedure. The usability evaluation was completed in two 60-minute sessions at a University of Chile laboratory. In each one of the sessions, the users interacted with the software for 25-30 minutes in order to evaluate the effectiveness of the interaction with the buttons on the pocketPC, the utility of the circular menus and the clarity of the sound support.

Each session involved the following steps: (1) *Introduction to the software.* The functions of the software application and its use through the pocketPC buttons are explained to the participant. (2) *Interaction with the software.* The users try out the functions of *AudioTransantiago* and the use of its buttons. At this point they also plan a trip as their final task. This trip is defined arbitrarily in order to be used in the evaluation of the cognitive impact. (3) *Documentation.* The session is documented in detail through the use of photographs, and (4) *Evaluation.* The Software Usability Questionnaire is applied. Based on the recommendations suggested by the participants, the software was modified, redesigning it in order to improve its usability.

3.1.4 Results. Quantitative results were obtained and these are summarized in Figure 3. The closed questions were evaluated on a point system with values between 1 and 10, 10 being the highest. On average, the values obtained for all the items were quite satisfactory, obtaining an average of over 9 points for all of them. The points assigned by the totally blind users were 10 for all the questions, while those users with residual vision gave out slightly lower points (average 9.02).

The "Satisfaction" category obtained an average score of 9.53 points. The statements that obtained the highest scores in this category, for both totally blind users and those with partial vision, are, "I would recommend this software to other people" (10 points in both cases) and "I like this software" (10 points and 9.3 points respectively). In the "Control and Use" category, an average score of 9.57 points was obtained, and those statements that received the highest scores, indifferent to the kind of user, were "The software is motivating" and "The software adapts to my pace". From this last statement we can gather that the user makes all of his/her consultations whenever he/she finds it convenient. The sounds obtained an average score of 9.28 points, in which the statement, "The sounds of the software are clearly identified" received a score of 9.33 points for users with partial vision and 10 points for the totally blind users.

For those users with partial vision, the graphic interface used in the software complements the sounds and helps to transmit information to them. This interface was evaluated with an average score of 9.67 points.

From the open questions, significant qualitative information was obtained. Among this information, we point out the fact that the participants did not have any major difficulties with using the buttons on the devices: it only took a couple of minutes of use for them to memorize the functions of each one of the buttons.

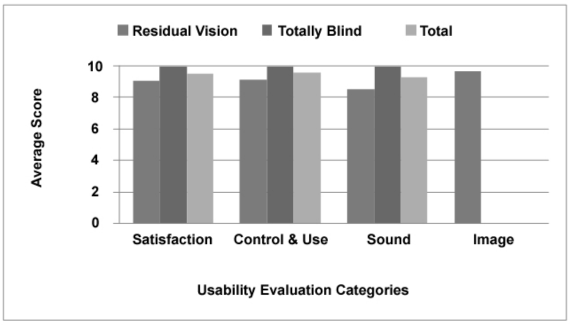


Figure 3. *Usability evaluation results for AudioTransantiago.*

The circular menus were qualified as useful, in that they allowed the users a more natural navigation by using the up and down buttons on the pocketPC, and it also helped to save time in searching through the menus that have a lot of options.

With respect to the audio, the participants pointed out that the TTS was well chosen, in that it synthesizes the texts quickly and clearly, and the voice is agreeable. The supporting sounds are clearly identifiable and provide clues on the actions that the user is taking at each moment. It is also worth mentioning that the users with partial vision mentioned that the colors of the graphic interface were well chosen, in that they produce a high level of contrast that facilitates its visualization, which redounds to extra help in the use of the software. They also mentioned the use of having images of the stops along the routes, which can help to identify them during the trip, which was implemented in the second iteration of the software development.

3.2 Cognitive Evaluation

3.2.1 Participants. The sample for the cognitive evaluation was made up of 4 legally blind participants, between the ages of 19 and 32 years old, residents of Santiago de Chile, and of which 3 were totally blind and one had residual vision. Case 1 was 26 years old, male, and totally blind (retinitis pigmentosa), case 2 was 27 years old, male and totally blind (bilateral atrophy of the optic nerve), case3 was 19 years old, female and with residual vision (retinitis pigmentosa), and case 4 was 32 years old, male and totally blind (retinitis pigmentosa). Two special education teachers also participated, which are specialists in visual disabilities, and one engineer who is an expert in usability evaluation.

3.2.2 Instruments. For the cognitive evaluation a route evaluation scale was used, with 14 statements designed specifically to study the ability of the users to solve problems by means of a Likert scale with the following response parameters: “Always”, “Almost Always”, “Occasionally” and “Never”. Statements were: Identifies/recognizes the streets on which the bus travels, identifies/recognizes the nearby parallel or perpendicular streets, able to relate points of interest with streets or stops with regards to the proximity to the destination, able to anticipate the stops using the software application, anticipates arrival to the end point of the route, reaches the planned destination successfully, understands the information provided by the software application and uses it correctly, able to orient his/herself spatially with the information provided by the tool, orients oneself according to cardinal notions of space by using the software application, appropriately plans his/her route, follows the planning process step by step, using AudioTransantiago, anticipates and avoids possible conflictive situations, identifies and reacts/acts clearly and decisively when faced with one or more problems that occur during the journey, and able to integrate the information from the environment and from the software, using if efficiently to arrive at the destination. These statements were designed by considering and adapting those currently used by O&M specialists in centers for the blind. Together with this guideline, an interview was designed for application after the trip, using open questions oriented at capturing, in detail, the difficulties experienced during the test and the users’ opinions with regards to the software. Some of the questions included in the interview are: Did using this software give you any degree of confidence in making your trip? Do you consider the use of this system to have any advantages for the legally blind population? What abilities do you consider that you put into practice when using the device (pocketPC) with the software?

3.2.3 Procedure. The cognitive evaluation was completed during 4 practical work sessions over a 2-month period. In each one of these sessions, a route was taken on board a bus, during which each user made use of the software individually in order to orient themselves and reach the final destination. Each user made just one trip. This trip was previously planned using the software (in the prototype evaluation session) and consisted of a distance of approximately 2.3 kilometers (see Figure 4A). Cognitive evaluation sessions lasted approximately 2.5 hours per user, a time which included an initial explanation about how to use the software, the functions of different buttons and the way to use it during the trip, the bus ride itself, and the application of the instruments.

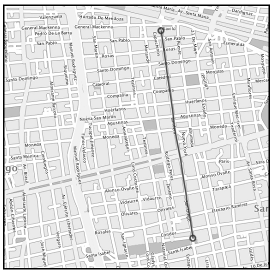
(A)  (B) 

Figure 4. (A) *Map of the route taken* (B) *Cognitive evaluation in a microbus, using AudioTransantiago*

The user was accompanied by two special education teachers, which are specialists in visual disabilities, and one project engineer, who gave out indications before beginning the journey and during the trip, always and only when the user asked for some help that was beyond the information provided by the software. During the trip, the facilitators evaluated different aspects of the user's performance by using the previously described evaluation guideline. After the trip, the user was interviewed on his/her experience (see Figure 4B).

3.2.4 Results. When the level of the users' problem solving skills as a result of having used *AudioTransantiago* was measured, relevant results were achieved, reaching 90% achievement in resolving orientation and mobility tasks. On average, the users obtained 39 out of a total of 42 points on the evaluation scale. The users were able, only on certain occasions, to relate significant landmarks to their respective streets and/or bus stops. This is due to the fact that, for each landmark, the software gives 4 horizontal streets and 4 vertical streets to the point, this being too much information to be able to remember. The users recommend using only 2 streets respectively. In addition, they were able to relate the distance from their final destination to the different landmarks. All together, the user is able to achieve a certain degree of autonomy in identifying places, planning certain routes and being able to get to their destination, which is the key objective of every bus ride.

The posterior interview provided valuable information: of the 4 users, only one had previously taken the route used, and had done so only partially. In addition, they indicated that the software was a real help in facilitating their location, in that the contextual information on each stop allowed them to identify approximately the area in which they were traveling, without necessarily knowing that area. With regards to a comparison between making the trip with or without the software, one of the users stated, "*The software indicates surrounding streets, something that one generally doesn't know or remember. That makes a notable difference, especially if you don't know the route; also, depending on the person, one can anticipate when to get off.*"

As far as the advantages that the users appreciate in the software, they commented: "*The information about the landmarks that it (AudioTransantiago) has is key, they are very orienting, it gives you a pretty practical map of the route to be followed.*", *"…it gives us information on what is all around us that we don't know.*", "*It makes you more independent of other people, because if I do everything right and concentrate on the route, I can get to my destination without any problems…*".

With regards to the degree of confidence that the software provided for making the trip, the users all agreed that the software provided them with a certain degree of security, and that they felt oriented within the span of the trip, but that they had some difficulties due to the attention that the software requires. One of them mentioned, "*The information that it provided me was good and precise, and let me know where I was. The stops can get all mixed up with each other, but it is just a matter of knowing where you are and paying attention to the distances and blocks between them. It's easy to use. It requires 100% concentration, which makes it hard to talk to people on the way.*"

When they were asked, "Do you consider the use of this system to have any advantages for the legally blind population?" one of the users responded, "*Yes, knowing the surroundings of the stop, the main streets that surround it such as those that are parallel or perpendicular to the north and south is useful, because it allows you to anticipate everything. If you plan the trip well, you can have mental clarity in as much as the journey and the time to get off.*"

According to interviewees, when they were asked about which abilities they considered having used when using the pocketPC with *AudioTransantiago*, they mentioned: attention, analysis, distinguishing (between stops), calculating or estimating distances, auditory memory, concentration, orientation and spatial location.

Among the potential difficulties that the users estimate could affect the use of the software is the possibility that the bus drivers not stop at all the stops along the route, or that they make stops at places besides the normal stops, which would confuse the users and negatively alter their planning. One user said, "*I don't know, it's just that they don't respect the stops…*" In addition, some participants need certain commodities in order to use the software easily, and others fear that the devices will not fulfill their roles perfectly and fail during the trip. One user commented, "*What if the battery runs out during the trip? It's necessary, as far as possible, to be sitting down, because holding oneself up with a cane is complicated, for which reason it could sometimes be difficult to concentrate.*"

With respect to the question, "What kind of solutions do you imagine when faced with these difficulties?" the users said that getting information from other passengers on the bus or from the driver could help to relocate themselves on the route. One of the users mentioned, "*Concentration is necessary at all times, especially because you are the one working the machine. The idea is not to put all the responsibility in the device, rather to complement it with ones own strategies*."

Finally, the blind participants that used *AudioTransantiago* are used to orienting themselves according to the cardinal directions, unlike the majority of blind people who orient themselves better through standard directions (left, right, straight, back). For this reason, the participants mentioned the need to have information about streets and surrounding places by their cardinal directions, because the way in which the information is currently presented in the software, it is necessary for them to have a certain dominion over the place in which they are located; using the cardinal directions, however, would be much easier.

4. CONCLUSIONS

The objective of this study was to determine if the fact of having contextual spatial information on the stops that make up a bus ride makes the use of urban transportation possible in an autonomous and efficient manner, improving the mobility and orientation of the user. In order to achieve this objective the software *AudioTransantiago* was designed, developed and evaluated with blind users, allowing users with visual impairments to orient themselves and move about on the trips made using the public transport system of buses in Santiago de Chile.

With the evaluation of the *AudioTransantiago* prototype, we were able to determine that the use of a pocketPC was appropriate for the end goals of this study, in that the participants learned to use the device without any major difficulties, demonstrating a high level of skill in the use of the buttons on the pocketPC. Also, the use of the audio system, both the synthesized voice and the non-verbal sounds, was well accepted by the users in which the natural sound of the TTS and the clarity of the sounds in general were highlighted.

All the users performed well on their trips and in the ways in which they dealt with them. In dealing well with the trips, they were able to achieve a higher degree of autonomy and improve the decision-making skills necessary to move about in the city. This was facilitated to a great degree through the use of the problem-solving methodology, which the users proved to dominate adequately.

The users were able to establish relationships between the stops on the trip and their respective nearby points of interest. This allowed them a certain degree of independence in planning trips, identifying places and being able to get to a destination, which was the main objective of the entire trip.

For the users of *AudioTransantiago* it is a powerful tool, due to the information on the environment that it provides to a legally blind user, and thanks to which they can anticipate things in advance and achieve an effective journey. At the same time, *AudioTransantiago* allows them to be aware of the environment that they are passing through, the trajectory that they are on and where they have to get off the bus, being able, as such, to make decisions about their route. All in all, the users were able to move around a lot more autonomously. As such, they improved their orientation and mobility skills on the bus transportation system through problem solving and the completion of proposed tasks.

As in all projects in which assumptions are made to be able to model situations, *AudioTransantiago* is dependent on the appropriate behavior of the bus drivers. If the drivers make stops at places that are not official stops, or if they skip one or more stops, they produce inconsistencies between the model and reality, and therefore the users of the software could become easily disoriented.

Some aspects to take into account in order to improve the program are to increase the amount of contextual information incorporated into the software (due to the time available the software was tested using only a reduced amount of information), make the planning of trips that involve the use of more than one route possible, and to incorporate the Metro network into the system.

Finally, it is necessary to make tests with more complex routes, and in more complex scenarios. A detailed analysis of the use and effect of this tool would allow us to clarify that a simple method without great technological requirements is able to support blind users' autonomy when moving about from one place to another in the city.

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Finger spelling recognition using distinctive features of hand shape

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ABSTRACT

The authors have been developing a glove based input device, called “Stringlove”, recognizing finger shapes by adapting for several shapes pointing an angle of each finger joint. A research group reports on the sign language linguistics features to distinguish finger shapes, and advance to make it practicable to engineering. This paper mentions that the method of recognition of finger shapes was examined by using the developing equipment. According to a preliminary experiment, it has been suggested that the present method has a good possibility to improve a rate of recognition of finger shapes.

1. INTRODUCTION

The communication barrier is serious problem for the hearing impaired in their social lives. To overcome the problem, several kinds of recognition methods or sign language recognition system have been developed. However, to recognize sign language, it is necessary to capture movements or hand shape of sign language. Thus, a motion capture system uses to obtain motion data or hand shape data of sign language.

The glove-based input device, one of component of motion capture system, use to measure hand shape or flexion/extension of hand or fingers. This glove sensor has been utilized in sign language recognition researches. However, such a motion capture systems with high performance are very expensive. Therefore, their sensor’s cost prevents groups of researchers from developing the sign recognition system, sign information system, translation system between sign language and phonetic language.

We have developed a glove-based input device, called “Stringlove” to realize the consumer price of glove sensor (Kuroda et al 2004). The glove sensor equips 24 inductcoders and nine contact sensors. It can measure joint flexion/extension of fingers and thumb, adduction/abduction angles of fingers and thumb, and wrist’s flexions, and also detect the contact position between fingertips of fingers and one of thumb. It also encodes finger shape into sign notation code by using embedded DSP. This function could decrease CPU load of computer as it seems that the processing of sign language recognition is heavy CPU load for main computer. However, this function cannot recognize hand shape but finger shape.

To improve this function of Stringlove, this paper describes a method to recognize hand shape of finger spelling with the distinctive features of hand shape of Japanese Sign.

2. RELATED WORK

Many researchers have proposed different methods to recognize hand shapes of gesture or finger spelling. These studies use either vision-based methods or glove-based methods.

A vision-based recognition system has advantages that user does not use special device such as glove, or that user’s motions are not limited comparing with the use of glove. But, this recognition system also has a problem such as light condition. To overcome the difficult problem, there are several kinds of researches

In vision-based approaches, the hidden Markov model (Kirsti Grobel et al 1997, Thad Stamer et al 1998) or Dynamic Programming (Phillippe Dreuw et al 2006) was used to recognize sign words. A group of researchers proposed the method to recognize sings by using the depth data obtained from a time-of-flight camera (Fujimura et al 2006). A group of Canadian researchers proposed the method to recognize hand gesture by using sign linguistics of Stokoe (K. G. Derpanis et al 2004). Their proposed method with Stokoe's linguistic system showed a high recognition rate. It seems that information of sign linguistic is effective for hand shape recognition.

On the other hand, a glove-based recognition system is approaches to recognize hand shape or hand motion of sign language as it can operate under severe light conditions. It also obtains a hand motion or a hand shape directly, though, it is necessary to put on a glove-based input device or motion capture system.

In glove-based approaches, the method using Fussy-Min-Max neural network and Data-glove (J.S.Kim et al 1996) was proposed. A group of researchers developed a new glove-sensor and proposed the application to learn Korean Finger spelling by using K-mean method and their developed glove-sensor (Y.Lee et al 2007).

Though finger spelling recognition method is different, finger language recognition system with neural network for the handicapped aphasiacs was proposed (Y.F.Fu et al 2007). The finger language is not finger spelling but hand shape predefined a meaning sentence. To use input device of wearable computer, a new glove-based input device was proposed, and the application was developed to control some device, such as light by using the proposed glove-sensor (K.Tsukada et al 2004).

3. DISTINCTIVE FEATURES OF HAND SHAPE OF JAPANESE SIGN

A group of Japanese sign linguistic engineering researchers reported about distinctive features of hand shape of Japanese Sign (D.Hara et al 2006). The distinctive features have the following elements.

1) Hand shape consists of finger shapes and thumb shape in Japanese Sign Language (JSL). It defines that PIP and DIP become the same joint's state, flexion or extension. The finger shape and thumb shape are classified into four shapes because of joint structures of finger and thumb. That is, hand shape consists of finger shapes selected from the above four shapes in the distinctive feature of sign linguistic knowledge. Table.1 shows the four classified shape of finger and thumb. Here, MCP is Metacarpal Phalangeal joint, PIP is proximal interphalangeal joint and DIP is distal interphalangeal joint.

2) Finger and thumb, which is component of hand shape, are referred to as either "dominant finger" or "non-dominant finger". Here, "dominant finger" is defined as a group of important finger to compose hand shape of JSL. "non-dominant finger" is defined as a group of finger except finger in "dominant finger". Figure 1 shows an example of "dominant finger "and "non-dominant finger".

A hand shape of finger spelling in Figure.1 consists of finger shape and thumb shape. To compose of the hand shape, finger shapes of index, middle, ring and pinkie are important elements, because the changes of their finger shape show difference hand shape or difference finger spelling. Therefore, their fingers are referred to as "dominant finger" in sign linguistics, and thumb as "non-dominant finger".

Table.1. *Four classified shape of fingers and thumb.*

Joint (states)	MCP (flexion)	MCP (extension)
PIP,DIP (flexion)	finger shape of "CLOSE"	finger shape of "BEND"
PIP,DIP (extension)	finger shape of "FLAT"	finger shape of "OPEN"

3) The shape of fingers in "dominant finger" is all the same shape. The one of finger in "non-dominant finger" is also the same shape. For example, when one finger of "dominant finger" shows finger shape of "OPEN" in Table.1, the others of "dominant finger" also shows "OPEN".

4) The finger shape in "non-dominant finger" selects either finger shape of "OPEN" or one of "BEND" in Table.1.

The above features are a method to compose of hand shape of finger spelling under sign linguistics. It seems that the distinctive features are available to recognize hand shape of finger spelling using computer.

Therefore, the authors make use of these distinctive features of hand shape of JSL, and propose a hand shape recognition method based on the distinctive features in sign linguistics.

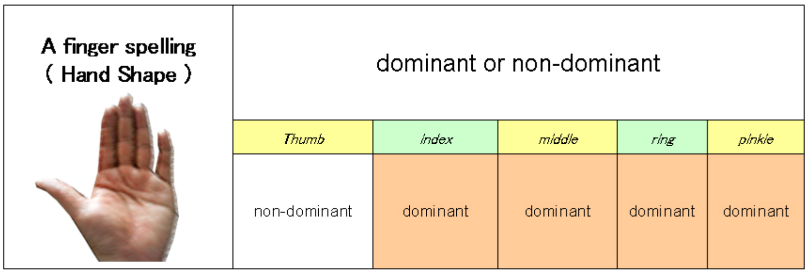

Figure 1. *Example of "dominant finger" and "non-dominant finger".*

4. METHOD

The authors only use notation codes obtained from Stringlove, and use a recognition method that the recognition system matches between the obtained notation codes and notation codes of a hand shape. However, in this case, the recognition rate of hand shape depends on the recognition rate of finger shape in Stringlove. The authors propose the method as shown Figure.2. Figure.2 shows a process flow of proposed method.

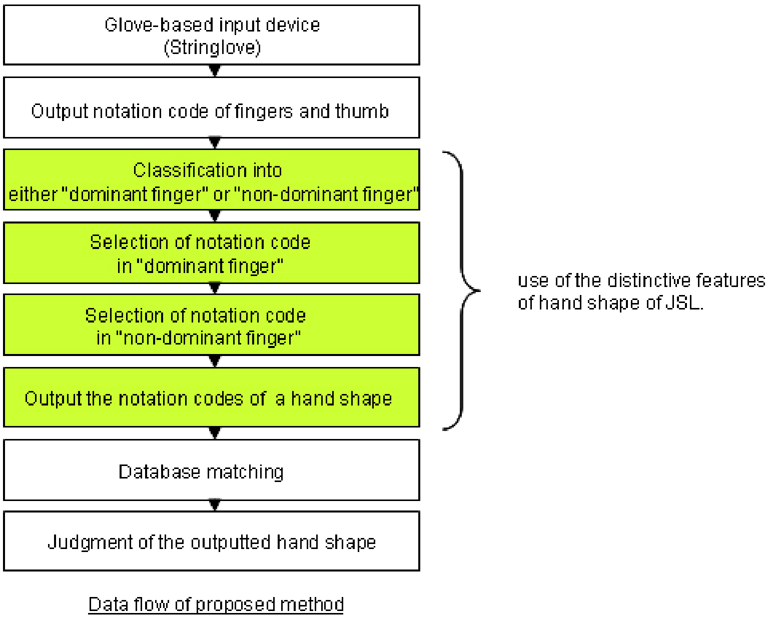

Figure 2. *Flow chart of proposed method to recognize hand shape with distinctive features.*

4.1 Classified into either "dominant finger" or "non-dominant finger"

Index finger is important finger under distinctive features of hand shape. A group of Japanese researchers classifies hand shapes in sign language into three patterns on the basis of index finger shape (Ichida 2005). There, the authors subjectively investigated number of fingers included in "dominant finger" and number of fingers included in "non-dominant finger" from all hand shapes of Japanese finger spelling.

The subjective investigation showed that index finger in "dominant finger" was 31 %, middle finger was 29%, ring finger was 19%, pinkie was 11% and thumb was 10%. From this investigation result and Ichida's research, it seems that index finger is included in "dominant finger" frequently. Whereat, the proposed method classifies finger shapes into either "dominant" or "non-dominant" on the basis of index finger shape. Each finger is classified into "dominant finger" in the following. It compares a shape of index finger with one of other fingers and the fingers of the same shape are included in "dominant finger" between shape of index finger and one of other fingers.

4.2 Selection of Notation Code in "dominant finger"

The proposed methods select notation code of "dominant finger" from the classified fingers as "dominant". It performs the following steps.

i) It compares finger shape of a finger with four finger shapes shown in Table.1.

ii) It confirms whether all finger shape of fingers included in "dominant finger" are the same shape. If all finger shape is same, it outputs the finger shape as a representative of "dominant finger".

iii) If all finger shape is not same, the highest occurrence rate of finger shape in "dominant finger" is outputted as the representative code of "dominant finger".

iv) If the occurrence rates of fingers in "dominant finger" are all same, a shape of index finger is outputted.

4.3 Selection of Notation Code in "non-dominant finger"

The proposed methods select a notation code of "non-dominant finger" from the classified fingers as "non-dominant". It performs the following steps.

i) It compares finger shape of a finger with four finger shapes shown in Table.1.

ii) If all finger shape is both the same shape and finger shape of either "BEND" or "OPEN", its finger shape is outputted as the representative of "non-dominant finger".

iii) If shapes of fingers in "non-dominant finger" are difference, the highest occurrence rate of finger shape is a representative candidate shape of "non-dominant finger". If the candidate one is one of either "BEND" or "OPEN", the finger shape of this candidate is outputted as the representative of "non-dominant finger".

iv) If a finger shape of "non-dominant" is not selected by using the above steps, it uses a combinatorial association between finger shapes in "dominant finger" and ones in "non-dominant finger" and determines the representative of "non-dominant finger".

The combinatorial association between finger shape of "dominant" and one of "non-dominant" is investigated in advance. The authors investigate the combination of finger shapes in 24 letters of Japanese Finger spelling. Figure.3 shows the investigation results. The combination of "CLOSE" in "dominant" and "OPEN" in "non-dominant" occurs with frequently, one of "BEND" in "dominant" and "CLOSE" in "non-dominant" does with slower frequency.

finger shape of "dominant"	finger shape of "non-dominant"	combinational rate
CLOSE	OPEN	high
OPEN	CLOSE	
BENT	BENT	
CLOSE	CLOSE	
OPEN	OPEN	
FLAT	OPEN	
BEND	CLOSE	low

Figure 3. *Combinational rate between dominant finger shape and non-dominant finger shape.*

4.4 Hand Shape Recognition

The proposed method obtains the correct finger shapes of hand shape in Finger spelling from Database and compares the obtained shapes data with finger shapes of both "dominant" and "non-dominant". It outputs the matched hand shape as recognition result, when all finger shapes are matched. Fingure.4 shows the matching rule to recognize hand shape of Finger spelling.

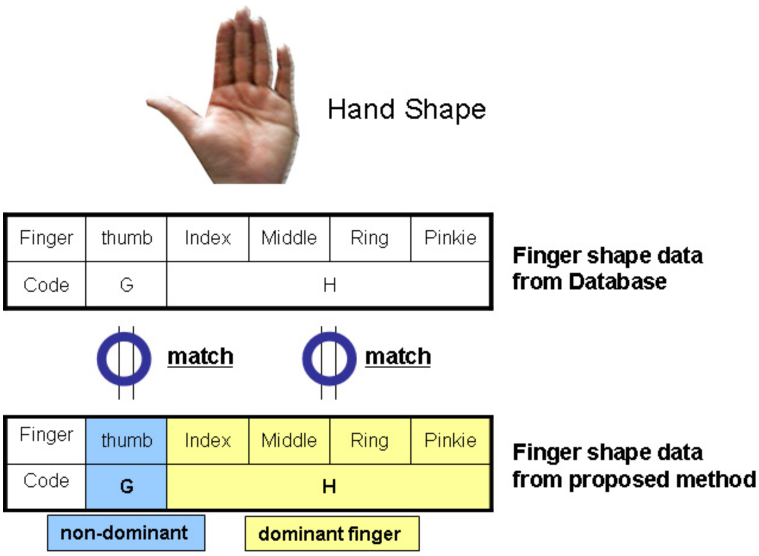

Figure 4. *Matching processing.*

5. PRELIMINARY EXPERIMENT

The proposed method is evaluated in a preliminary experimentation. This experiment compared recognition result without the proposed method, with the recognition result that the proposed method utilized

The preliminary experimentation preformed the following steps. A subject expressed six hand shapes of Japanese finger spelling by using Stringlove. The measurements were performed three times. The proposed method showed the notation codes of a hand shape from the measured data. Japanese finger spellings, which is used in this experiment, are “A”, “U”, “TE”, “FU”, “RO” and “WA”. Subjects are two persons, a male and a female.

Figure.5 shows the matching rates of six hand shapes. Case 1 does not use the proposed method and case 2 uses the proposed method. From the preliminary experiment result, it seems that the proposed method was effective in hand shape recognition of Stringlove.

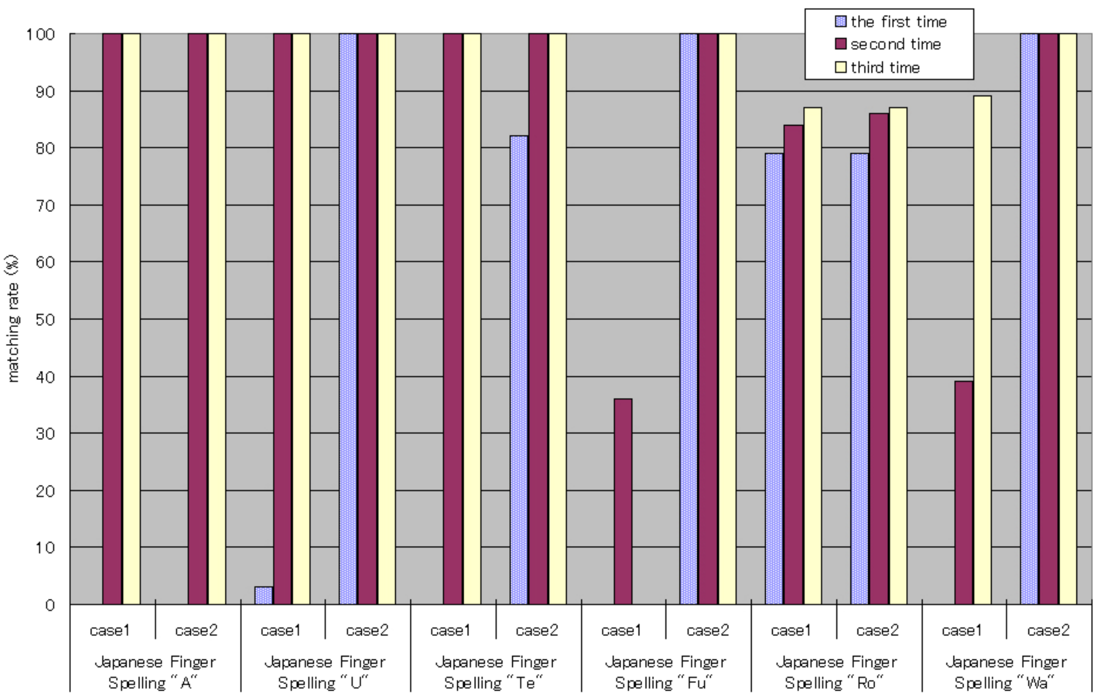

Figure 5. *A comparison result between matching rate of case 1 and one of case 2.*

In addition, the proposed method has the possibility to improve the matching rate of hand shape. In this paper, the progress rate was given by the following equation.

$$\text{progress rate} = \frac{(\text{matching rate of case1 - matching rate of case2})}{\text{matching rate of case1}} \times 100$$

A progress rate became as high as 1.79% in second time of Japanese Finger spelling "Ro", and became as high as about 12% in third time of Japanese Finger spelling "Wa". The recognition rate of Japanese finger spelling except for "A" increased by near 80 %. It seems that the proposed method played a role in revising miss-recognized finger shapes. Therefore, comparing case 1 with case 2, the matching rate would increase in this experiment.

However, some matching rates were approximately same values in Japanese Finger spelling "A" and "Ro". The reason included that the probability of mismatched finger shape was higher than one of correct finger shape. Therefore, it is considered that the proposed method could not distinguish these hand shapes correctly.

6. CONCLUSIONS

This paper proposed the recognition method with distinctive features of hand shape of JSL in order to improve the hand shape recognition of Stringlove. The proposed method used distinctive features of sign linguistics. The proposed method classified the fingers of a hand into two categories; "dominant finger" and "non-dominant finger", and recognized finger shapes in each categories on the basis of distinctive feature of hand posture. The proposed method was evaluated in the preliminary experiment. The experimental result showed that the proposed method was an effective approach to improve the matching rate of Stringlove.

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Interactive training of speech articulation for hearing impaired using a talking robot

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ABSTRACT

This paper introduces a speech training system for auditory impaired people employing a talking robot. The talking robot consists of mechanically-designed vocal organs such as a vocal tract, a nasal cavity, artificial vocal cords, an air pump and a sound analyzer with a microphone system, and the mechanical parts are controlled by 10 servomotors in total for generating human-like voices. The robot autonomously learns the relation between motor control parameters and the generated vocal sounds by an auditory feedback control, in which a Self-organizing Neural Network (SONN) is employed for the adaptive learning. By employing the robot and its properties, we have constructed an interactive training system. The training is divided into two approaches; one is to use the talking robot for showing the shape and the motion of the vocal organs, and the other is to use a topological map for presenting the difference of phonetic features of a trainee's voices. While referring to the vocal tract motions and the phonetic characteristics, a trainee is able to interactively practice vocalization for acquiring clear speech with an appropriate speech articulation. To assess the validity of the training system, a practical experiment was conducted in a school for the deaf children. 19 subjects took part in the interactive training with the robotic system, and significant results were obtained. The talking robot is expected to intensively teach an auditory impaired the vocalization skill by directing the difference between clear speech and the speech with low clarity.

1. INTRODUCTION

Speech is one of the important media to communicate with each other. Only humans use words for verbal communication, although most animals have voices or vocal sounds. Vocal sounds are generated by the relevant operations of the vocal organs such as lung, trachea, vocal cords, vocal tract, tongue and muscles. The airflow from the lung causes the vocal cords vibration and generates a source sound, then the sound is led to a vocal tract to work as a sound filter as to form the spectrum envelope of a particular sound. The voice is at the same time transmitted to the human auditory system so that the vocal system is controlled for the stable vocalization. Various vocal sounds are generated by the complex articulations of vocal organs under the feedback control mechanisms using an auditory system.

Infants have the vocal organs congenitally, however they cannot utter a word. As infants grow they acquire the control methods pertaining to the vocal organs for appropriate vocalization. These get developed in infancy by repetition of trials and errors concerning the hearing and vocalizing of vocal sounds. Any disability or injury to any part of the vocal organs or to the auditory system might cause an impediment in vocalization. People who have congenitally hearing impairments have difficulties in learning vocalization, since they are not able to listen to their own voice.

Auditory impaired patients usually receive a speech training conducted by speech therapists (ST) (Boothroyd, 1973; Boothroyd, 1988; Erber and de Filippo, 1978; Goldstein and Stark, 1976), however many problems and difficulties are reported. For example, in the training, a patient is not able to observe his own vocal tract, nor the complex articulations of vocal organs in the mouth, then he cannot recognize the validity of his articulation nor evaluate the achievement of speech training without hearing the voices. Children take training at school during a semester, however it is not easy to continue the training during vacation and they get to forget the skill. The most serious problem is that the number of ST is not enough to give speech training to all the subjects with auditory impairment.

The authors are developing a talking robot by reproducing a human vocal system mechanically based on the physical model of human vocal organs. The robot consists of motor-controlled vocal organs such as vocal cords, a vocal tract and a nasal cavity to generate a natural voice imitating a human vocalization. For the autonomous acquisition of the robot's vocalization skills, an adaptive learning using an auditory feedback control is introduced.

In this study, the talking robot is applied to the training system of speech articulation for the hearing impaired children, since the robot is able to reproduce their vocalization and to teach them how it is improved to articulate the vocal organs for generating clear speech. The paper briefly introduces the mechanical construction of the robot first, and then the analysis of the autonomous learning will be described how the robot reproduces the articulatory motion from hearing impaired voices by using a self-organizing neural network. An interactive training system of speech articulation for hearing impaired children is presented, together with an experiment of speech training conducted in a school for deaf children.

2. HEARING IMPAIRED AND THE SPEECH TRAINING

Currently, a speech training for hearing impaired is conducted by speech therapists. They give specially-designed training programs to each patients by carefully examining the symptoms of impairment. In Japan there are about 360,000 hearing impaired people who are certified by the government, however by counting patients with mild symptoms and aged people with auditory disabilities, the number will be doubled to 600,000. On the contrary, the number of ST is approximately 10,000, which is far less than the number of the patients. Conventionally the training by a ST is conducted face-to-face by using a mirror to show the articulatory motions of inner mouth. Schematic figures to conceptually show the mouth shapes and articulatory motions are also employed for intuitive understandings of the speech articulations.

Figure 1 shows an example of an electronic speech training system WH-9500 developed by Matsushita Electric Industrial Co., Ltd. It is equipped with a headset with a microphone, and shows the difference of sound features together with an estimated vocal tract shape on the display, so that a trainee could understand his own vocalization visually. The system is large and requires technical knowledge and complex settings, and it is difficult for an individual patient to settle it at home. By examining the problems of the conventional training mentioned above, the authors are constructing an interactive training system, by which a patient engages in a speech training in any occasion, at any place, without special knowledge, as shown in Figure 2.

We are constructing a training system employing a talking robot. By using a self-organizing neural network, the robot reproduces an articulatory motion by listening to a subject's voice, and the phoneme characteristics are visually shown in a display, so that a trainee could recognize his own phoneme characteristics and the corresponding vocal tract shape by comparing with a target voice. Besides, to realize an interactive training and easy manipulation, the robotic training system is executed by a simple user interface.

3. CONSTRUCTION OF A TALKING ROBOT

Human vocal sounds are generated by the relevant operations of vocal organs such as the lung, trachea, vocal cords, vocal tract, nasal cavity, tongue and muscles. In human verbal communication, the sound is perceived as words, which consist of vowels and consonants.

The lung has the function of an air tank, and an airflow through the trachea causes a vocal cord vibration as the source sound of a voice. The glottal wave is led to the vocal tract, which works as a sound filter as to form the spectrum envelope of the voice. The fundamental frequency and the volume of the sound source is varied by the change of the physical parameters such as the stiffness of the vocal cords and the amounts of airflow from the lung, and these parameters are uniquely controlled when we speak or utter a song.

In contrast, the spectrum envelope, which is necessary for the pronunciation of words consisting of vowels and consonants, is formed based on the inner shape of the vocal tract and the mouth, which are governed by the complex movements of the jaw, tongue and muscles. Vowel sounds are radiated by the relatively stable configuration of the vocal tract, while the short time dynamic motions of the vocal apparatus produce consonants generally. The dampness and viscosity of organs greatly influence the timbre of generated sounds, which we may experience when we have a sore throat. Appropriate configurations of the vocal tract for the production of phonemes are acquired as infants grow by repeating trials and errors of hearing and vocalizing vocal sounds

(a) Appearance of WH-9600 (b) Headset with microphone

Figure 1. *An example of electronic speech training system.*

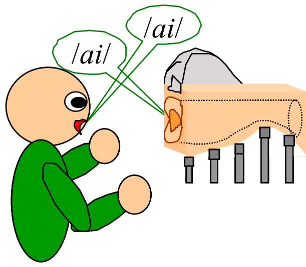


Figure 2. *Interactive training.*

The talking robot mainly consists of an air compressor, artificial vocal cords, a resonance tube, a nasal cavity, and a microphone connected to a sound analyzer, which correspond to a lung, vocal cords, a vocal tract, a nasal cavity and an auditory system of a human, as shown in Figure 3.

An air from the pump is led to the vocal cords via an airflow control valve, which works for the control of the voice volume. The resonance tube is attached to the vocal cords for the articulation of resonance characteristics. The nasal cavity is connected to the resonance tube with a rotational valve between them. The sound analyzer plays a role of the auditory system, and realizes the pitch extraction and the analysis of resonance characteristics of generated sounds in real time, which are necessary for the auditory feedback control. The system controller manages the whole system by listening to the generated sounds and calculating motor control commands, based on the auditory feedback control mechanism employing a neural network learning. The relation between the sound characteristics and motor control parameters are stored in the system controller, which are referred to in the generation of speech and singing performance.

3.1 Artificial Vocal Cords and Its Pitch Control

Vocal cords with two vibrating cords molded with silicone rubber with the softness of human mucous membrane were constructed in this study. Two-layered construction (a hard silicone is inside with the soft coating outside) gave the better resonance characteristics, and is employed in the robot (Higashimoto and Sawada, 2003). The vibratory actions of the two cords are excited by the airflow led by the tube, and generate a source sound to be resonated in the vocal tract.

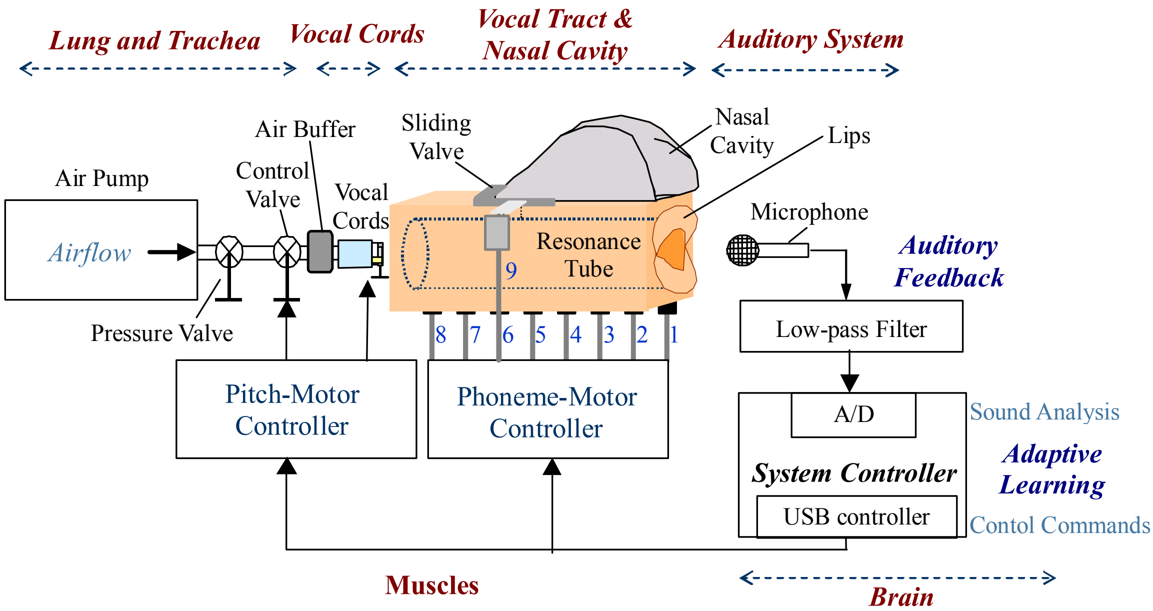


Figure 3. *Construction of the talking robot.*

The tension of vocal cords can be manipulated by applying tensile force to them. By pulling the cords, the tension increases so that the frequency of the generated sound becomes higher. The relationship between the tensile force and the fundamental frequency of a vocal sound generated by the robot is acquired by the auditory feedback learning before the singing and talking performance, and pitches during the utterance are kept in stable by the adaptive feedback control (Sawada and Nakamura, 2004).

3.2 Construction of Resonance Tube and Nasal Cavity

The human vocal tract is a non-uniform tube about 170 mm long in man. Its cross-sectional area varies from 0 to 20 cm^2 under the control for vocalization. A nasal cavity with a total volume of 60 cm^3 is coupled to the vocal tract. Nasal sounds such as /*m*/ and /*n*/ are normally excited by the vocal cords and resonated in the nasal cavity. Nasal sounds are generated by closing the soft palate and lips, not to radiate air from the mouth, but to resonate the sound in the nasal cavity. The closed vocal tract works as a lateral branch resonator and also has effects of resonance characteristics to generate nasal sounds. Based on the difference of articulatory positions of tongue and mouth, the /*m*/ and /*n*/ sounds can be distinguished with each other.

In the mechanical system, a resonance tube as a vocal tract is attached at the sound outlet of the artificial vocal cords. It works as a resonator of a source sound generated by the vocal cords. It is made of a silicone rubber with the length of 180 mm and the diameter of 36 mm, which is equal to 10.2 cm^2 by the cross-sectional area as shown in Figure 4. The silicone rubber is molded with the softness of human skin, which contributes to the quality of the resonance characteristics. In addition, a nasal cavity made of a plaster is attached to the resonance tube to vocalize nasal sounds like /*m*/ and /*n*/.

By actuating displacement forces with stainless bars from the outside, the cross-sectional area of the tube is manipulated so that the resonance characteristics are changed according to the transformations of the inner areas of the resonator. Compact servo motors are placed at 8 positions x_j (j = 1-8) from the intake side of the tube to the outlet side, and the displacement forces $P_j(x_j)$ are applied according to the control commands from the phoneme-motor controller.

A nasal cavity is coupled with the resonance tube as a vocal tract to vocalize human-like nasal sounds by the control of mechanical parts. A rotational valve as a role of the soft palate is settled at the connection of the resonance tube and the nasal cavity for the selection of nasal and normal sounds. For the generation of nasal sounds /*n*/ and /*m*/, the rotational valve is open to lead the air into the nasal cavity.

By closing the middle position of the vocal tract and then releasing the air to speak vowel sounds, /*n*/ consonant is generated. For the /*m*/ consonants, the outlet part is closed to stop the air first, and then is open to vocalize vowels. The difference in the /*n*/ and /m/ consonant generations is basically the narrowing positions of the vocal tract.

In generating plosive sounds such as /*p*/, /*b*/ and /*t*/, the mechanical system closes the rotational valve not to release the air in the nasal cavity. By closing one point of the vocal tract, air provided from the lung is stopped and compressed in the tract. Then the released air generates plosive consonant sounds like /*p*/ and /*t*/.

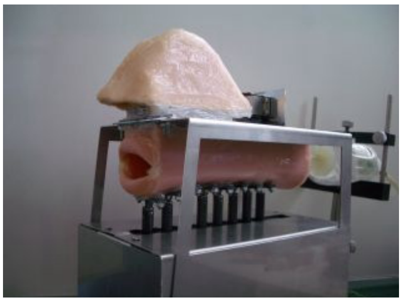


Figure 4. *Talking robot.*

4. METHOD OF AUTONOMOUS VOICE ACQUISITION

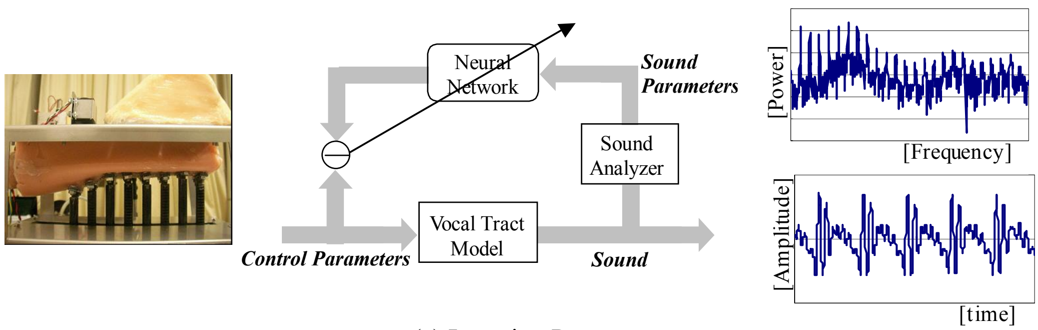
We pay attention to the ability of a neural network (NN) to associate sound characteristics with the vocal tract shape. By autonomously learning the relation, it will be possible to estimate the articulation of vocal tract, so that the robot can generate appropriate vocal sounds. The NN is expected to work for associating the sound characteristics with the control parameters of the motors as shown in Figure 5. In the learning phase, the NN learns the motor control parameters by inputting power spectra of sounds as teaching signals. The network acquires the relations between sounds and the cross-sectional areas of the vocal tract (Figure 5(a)). After the learning, the NN is connected in series into the vocal tract model as shown in Figure 5 (b). By inputting the sound parameters of desired sounds to the NN, the corresponding form of the vocal tract is obtained.

A Self-Organizing Neural Network (SONN), which consists of an input layer, a competition layer, a hidden layer and an output layer, is employed in this study to adaptively learn the vocalization skill, as shown in Figure 6. The links between the layers are fully connected with learning coefficient vectors $\{V_{ij}\}$, $\{W^1_{jk}\}$ and $\{W^2_{kl}\}$. The number of the cells in the input layer is set to 10, in accordance with the number of the sound parameters consisting of 10th order cepstrum coefficients (Sawada, 2007) extracted from vocal sounds generated by random articulations of the robot mouth. The number of the output layer cells is 8, which is the number of the motor-control parameters to manipulate the vocal tract. The number of the cells in the hidden layer and the competition layer is determined by considering the number of learning patterns.

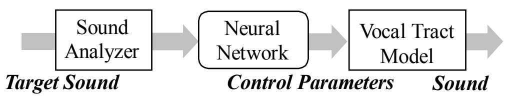
In the learning phase, the relations between the sound parameters and the motor control parameters are established. In the speech phase, motor control parameters are recalled by inputting target voices. In this study, the learning of the sound parameters in the competition layer is called "upward learning", and a topological map is expected to be established in the competition layer by the self-organizing map (SOM) learning. The learning of the relation between the SOM and the motor control parameters is called a "downward learning", which associate phonetic features with vocal tract shapes.

5. ANALYSIS OF ACQUIRED SOUNDS

In the learning phase, sounds randomly vocalized by the robot were mapped on the map array. After the learning of the relationship between the sound parameters and the motor control parameters, we inputted human voices from microphone to examine whether the robot could speak autonomously by mimicking human vocalization. Same vowel sounds were mapped close with each other, and five vowels were well categorized according to the differences of phonetic characteristics. Two different sounds having large difference of phonetic features are located far with each other. In this manner, topological relations according to the difference of phonetic features were autonomously established on the map.



(a) Learning Process



(b) Running Process

Figure 5. *Neural network in mechanical model.*

Figure 7 shows the results of acquired spectra, in comparison with actual human voices. By comparing the robot voices with human, phonetic characteristics of Japanese vowels were well reproduced by the topological relations on the feature map. Human vowel /*a*/ has the first formant in the frequency range from 500 to 900 Hz and the second formant from 900 to 1500 Hz, and the robotic voice also presents the same formants. In the listening experiments, most of the subjects pointed out that the generated voices have similar phonetic characteristics to the human voices. These results show that the vocal tract made by silicone rubber has the tolerance of generating human-like vocalization, and the neural network learning of the voice acquisition was successfully achieved.

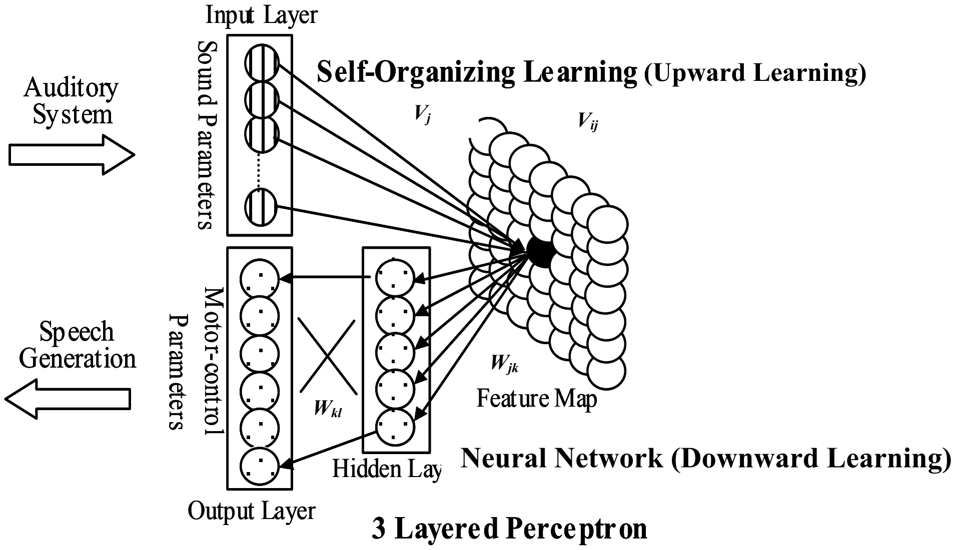


Figure 6. *Structure of self-organizing neural network.*

We also examined a topological structure autonomously established on the feature map by the SOM learning. Figure 8 (a) shows an example of a topological map established by the learning. By choosing 6 grids from the /*a*/ area to /*i*/ area shown by a dotted arrow, a voice transition between the two vowels was studied. Figure 8 (b) shows the transition of control values of 8 motors from /*a*/ vocalization to /*i*/ vocalization. Each value is transiting smoothly from the shape of /*a*/ to /*i*/, and this proved that the robot successfully established the topological relations of phonetic features of voices reproduced by the articulatory motions.

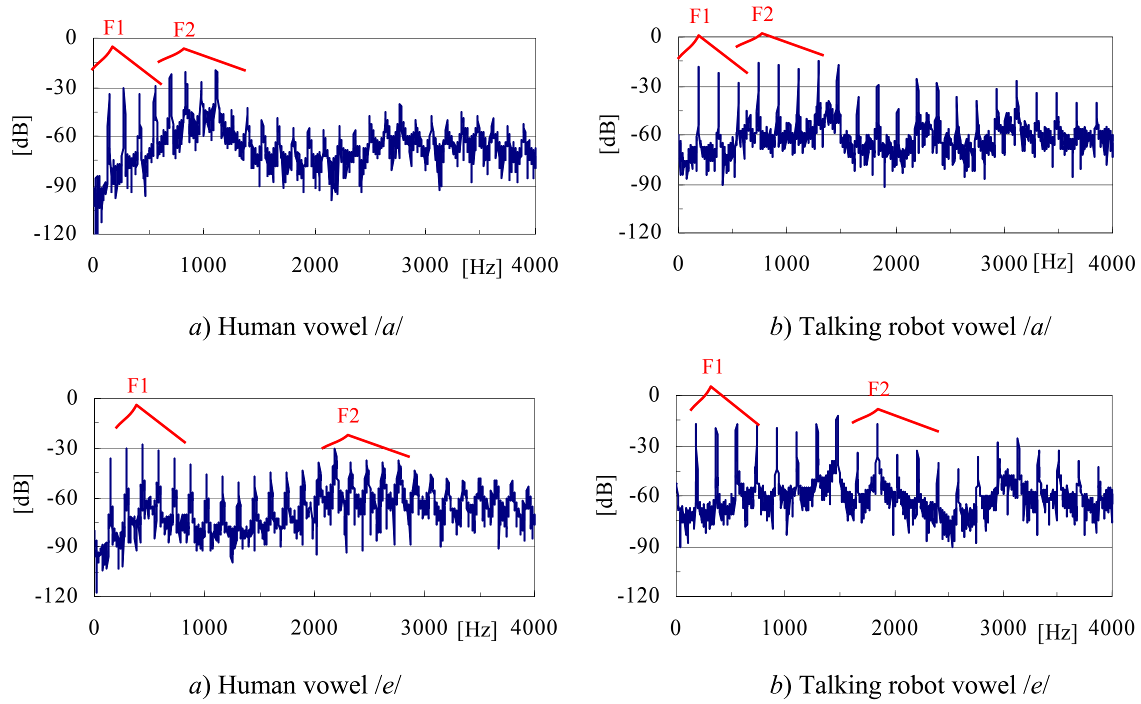
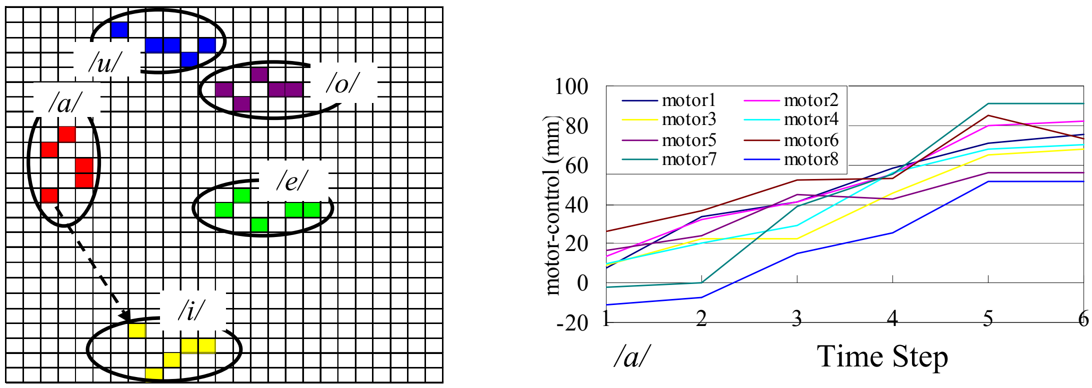


Figure 7. *Comparison of spectra.*



a) Result of Japanese vowel mapping b) Speech articulation from /a/ to /i/

Figure 8. *Acquired topological map and voice transition.*

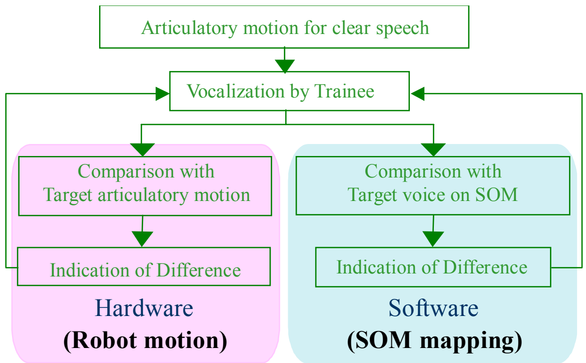


Figure 9. *Flow of Speech Training.*

6. INTERACTIVE TRAINING OF SPEECH ARTICULATION FOR HEARING IMPAIRED

6.1 Training Methods

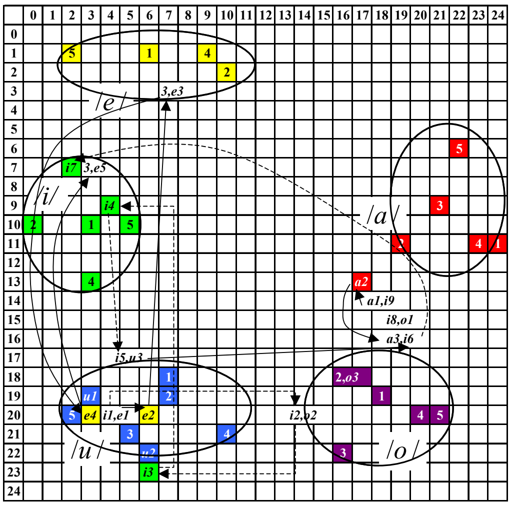
The talking robot is able to reproduce an articulatory motion by only listening to a voice, and we are developing a training system which teaches auditory impaired children how clear speech is generated by interactively directing articulation of inner mouth.

The training is given by two approaches; one is to use the talking robot for showing the shape and the motion of the vocal organs (hardware training), and the other is to use a topological map for presenting the difference of phonetic features of a trainee's voices (software training). Figure 9 shows the flow of the training. At first, an ideal vocal tract shape is presented to a trainee by the talking robot, and the trainee tries to articulate the vocalization referring to the robot. Then, by listening to the trainee's voice, the robot reproduces the trainee's estimated vocal tract shape, and directs how the trainee's voice would be clarified by the change of articulatory motions, by intensively showing the different artiulatory points. The trainee compares his own vocal tract shape and the ideal vocal tract shape, both of which are shown by the articulatory motions of the robot, and tries to reduce the difference of the articulations. The system also presents phonetic features using the topological map, in which the trainee's voice and the target voices are displayed. During the repetition of speech and listening, the trainee recognizes the topological distance between his voice and the target voice, and tries to reduce the distance. In the training, a trainee repeats these training processes for learning 5 vowels.

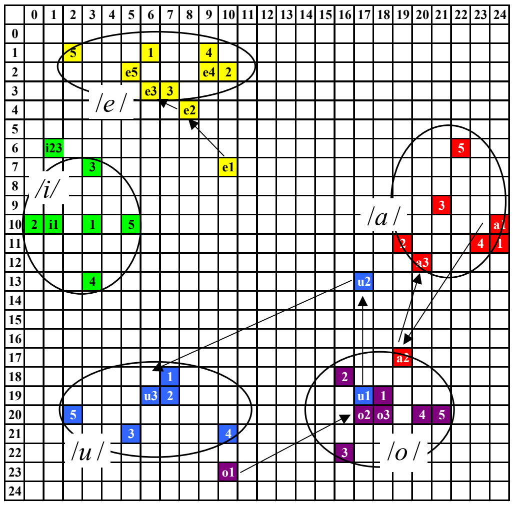
A training experiment was conducted in a school for the deaf children. 12 high school students and 7 junior-high school students (19 students in total) were engaged in the experiment.

6.2 Training Results

Figure 10 shows the result of speech training conducted by two subjects #a and #b. Labels with numbers 1 to 5 show the vowels vocalized by able-bodied subjects #1 to #5, respectively, and the grids indicated by the numbers encircled with vowel names present the area of clear phonemes. During the training, the trainees practiced the vocalization to try to bring their voices fall into the circles of each vowel. "*a*1" means the first vocalization of vowel /*a*/ by the subject, and the arrows show the transition of trials to achieve the clear vocalization. A label "*a*123" in one grid, for example, means that the vocalization stayed in the same phonetic characteristics during the first to the third trials.

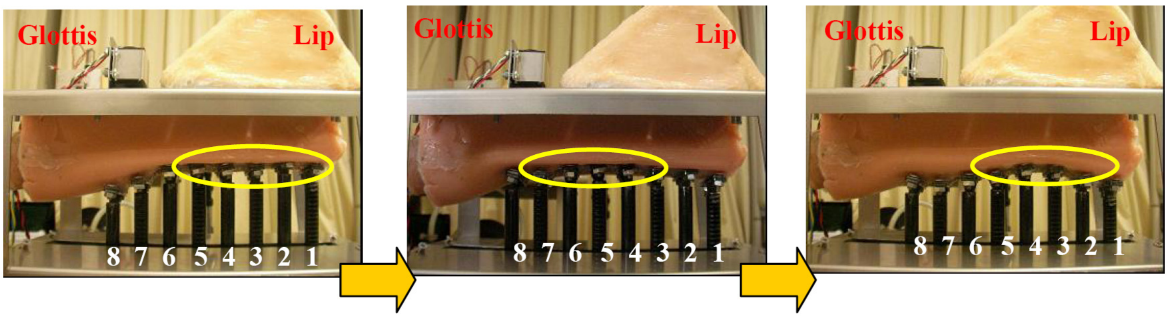


(b) Subject #a

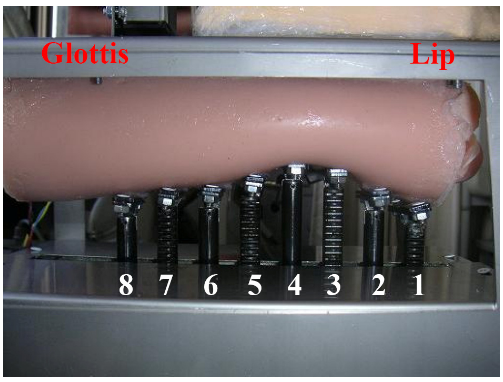


(c) Subject #b

Figure 10. *Training results of two subjects #a and #b.*



(a) Step 1 (b) Step 2 (c) Step 3



(d) Vowel /*e*/ by able-bodied speaker

Figure 11. *Progress of /e/ Vocalization by Subject #b*

In the experiment, subject #a could not learn all the ideal vowels. In the training of vowel /*a*/, for example, his first voice fell in the location between the /*a*/ and /*o*/ vowel area. He made trials to bring his voice to the /*a*/ area by referring to the robot vocalization, however he could not achieve it. On the other hand, subject #b could successfully achieve the training to acquire the vocalization skill of five Japanese vowels, after the several trials. Figure 11 shows the progress of the vocal tract shapes of the vowel /*e*/ vocalization in the training of Subject #b. The circles show the articulation points for the vocalization of /*e*/, which the subject intensively tried to articulate during the training. After several trials, he could successfully acquire the vocalization, which is almost the same with the vocalization given by an able-bodied speaker.

Through the training, 13 students out of 19 could achieve the clear vocalization, and all the students at least learned better vocalization than that before the training. Most of the subjects reported that they enjoyed the training using the talking robot, and wanted to continue it in the future.

7. CONCLUSIONS

A talking robot and its articulatory reproduction of voice of hearing impaired was described in this paper. By introducing the adaptive learning and controlling of the mechanical model with the auditory feedback, the robot was able to acquire the vocalization skill as a human baby does in a speech training. The robot was applied to introduce a new training system for auditory impaired children to make an interactive training of speech articulation for learning clear vocalization. The robotic system reproduces the articulatory motion just by listening to actual human voices, and a trainee could learn and know how to move the vocal organs for the clear vocalization, by observing the motions directed by the talking robot.

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ICDVRAT 2008

Session VIII

Virtual Reality Methodologies II

Chair: Miguel Santos

Examination of users' routes in virtual environments

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ABSTRACT

We developed 3 virtual environments (VEs): a VR gallery, a VR store and a VR labyrinth for the investigation of the users' routes in these VEs. In this article we examine the matching of these tours with two developed utilities. From the results we want to draw the inference to the practical development of the virtual environments for defined groups of users. We examined left-handed, right-handed persons and people who play often with VR games as well as people who play with VR games rarely or never. The VE and the developed testing frame software are adaptable for every disabled group's route examination.

1. INTRODUCTION

Nowadays virtual and 3D-workspaces are highly relevant at the development of graphical user interfaces (GUI). 3D menus, 3D-task switching are already services of the operating systems, although these are not virtual environments. These GUIs display depth only with shading and texturing. The advanced version of these GUIs is the 3D-workspace, where the 2D objects are displayed in perspective view. If a graphical object is far from the user, it takes less space on the display, and if it's pointed, the user gets closer to it, and it will be bigger on the screen. Hereby the 3D-workspace gives more space and comfortable navigation. Its improved version is the virtual reality, which is the most sophisticated method of information visualization, but special display devices (for example: head mounted displays) are needed to use this method, so that the user can move in a simulated 3D world. This is the most advanced form of the dialogue between the user and the computer. This kind of GUI makes a quick interaction possible, because the user gives continuous instructions and gets feedback from the computer.

If we want to develop usable, user friendly virtual environments, we have to know, how the users tour about them, to be able to set the priority between the functions of the system, which we develop. Therefore our primary goal was to investigate the users' routes. The developed testing frame software is usable for every disabled group's route examination.

Bagyal developed labyrinths to test the routes between left- and right-handed users in his thesis. He concluded that there is a significant difference in the navigation of users in virtual environments, caused by the handedness. (Bagyal, 2004) That is why we decided to divide our testers in left- and right-handed groups.

Tilinger investigated the same task with a fire-alarm- and a labyrinth simulation, complemented with the differences of the perception of information caused by handedness. He found no significant difference in the information-perception and he found only a slight difference in the behaviour in virtual environments of these groups (Tilinger, 2006).

Matrai created an algorithm to investigate the users' navigation on web pages. It shows the significant orders and places of the clicks of the users. (Mátrai, 2008) It can be applied for our goal, to determine the important route by the examination of the users' routes, in a VE. Based on above we wanted to investigate the navigation routs in more detail, to be able to provide best practise for every type of disability.

2. DEVELOPING

A test application was used during the examination of the routes, which contains three virtual environments: a gallery, a labyrinth and a store.

The virtual environments of the testing application were developed with Alias Maya 7.0. This software hasn't got a feature for interactivity, that's why a 3D-engine was needed, with which the frame-program was developed. The Irrlicht3D is an open source engine, which has a GUI library too. It was written in C++, but it's programmable in most of the common languages (C++, C#, Java, Delphi), C++ was used during the development. The application has two tasks, to test and save the users' routes, and to evaluate them. That is why two modules have been developed. The tester module has a form, which asks the user's name, group and the VE. After clicking the start button, the test begins (Figures 1, 2, 3). Between the Maya and the Irrlicht3D the Object file format gave the compatibility. These files were imported into the IrrEdit, a utility of the Irrlicht3D, which gave a render feature for the environments, so with lights they became more realistic. The movements of the testers were exported into XML files, which can be used trough an import method by an evaluating program. The XML files were saved automatically.

The evaluating application was also developed in C++, using the GUI library of the Irrlicht3D. It also has a form, in which the evaluating person collects the routes into a file list, wherefrom the program reads and evaluates them. There are two ways to evaluate them. We developed an algorithm, which evaluates the differences between the routes and this algorithm characterises the evaluation with a Gini-index. The other one is Matrai's algorithm, used to determine the most significant route. The results are displayed in an XML file, for the further evaluations.

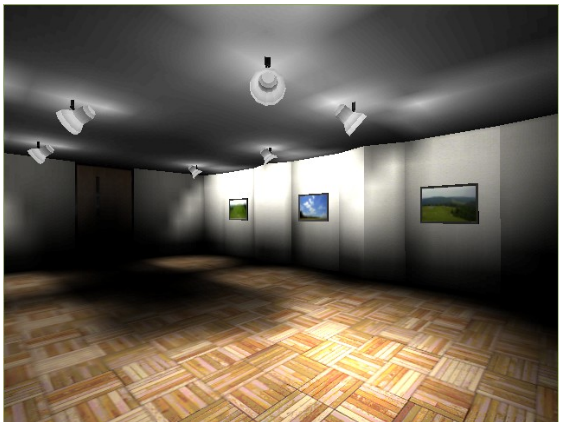

Figure 1. *View of the gallery.*

Figure 2. *View of the store.*

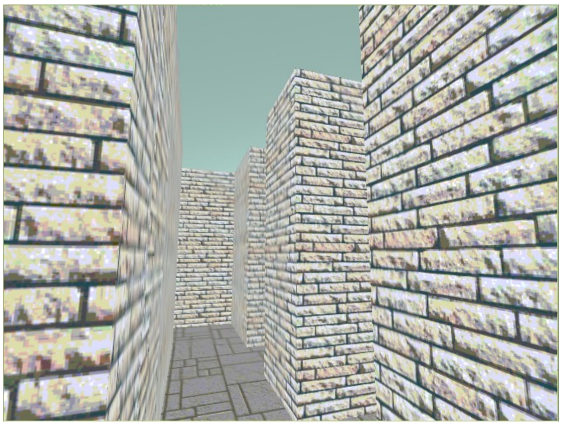

Figure 3. *View of the labyrinth.*

3. TEST ENVIRONMENTS

The virtual spaces were chosen to be simple environments of the tester's tasks. A gallery, a store and a labyrinth are good scenes for an easy, objective evaluation, where the routes can be noted. The task of the test-persons was to look at the objects of the gallery and of the store, as well as to find the exit of the labyrinth. These routes are only horizontal, there's no way to walk in the environment in height. The environments are developed to be symmetric, not to influence the testers in their movements (but the observer does not know that the VE is symmetric), and the viewable objects shall arouse their interests in an equal rate, too. The spaces are selectable for each examination; it's not necessary to use all of them at one occasion. All three VEs have the same floor-space, so the examination of the coordinates can be easily carried out. These coordinates are given by a grid, which can be set by a configuration file. If a point of the grid is touched by the tester, it will be noted in the structure of the going, so the path can be saved in a file at the end of the examination.

The task in the gallery (Figure 1) is to view 8 pictures in an arbitrary sequence. This environment gives a free space; no barriers are placed against the tester. In the store (Figure 2) a shelf was placed in the middle, so the space can only be walked in a circle from the left to the right or in the opposite direction. If the grid is smooth enough it's also possible to examine whether the path leads on the inner or outer side of the circle.

The task of the third space is to get out of the labyrinth (Figure 3). Although it's symmetric, it's possible to walk through it using two corridors, so the exit can be found in several ways.

4. EXAMINATIONS

The test users were divided in four groups, left-handed (9 persons), right-handed (7 persons), experienced (11 persons) and novice (5 persons) users of the VR applications. Most of the users were young and almost all of them were experienced in VR use. Because of the low participation, only a pilot-test was conducted. At the execution of the tests, the help of the examination leader was needed, because the application had to be introduced to the novice users. The experienced users accomplished the test on their own, trough the internet. The application was posted as an attachment of an e-mail, and they sent the results back the same way.

The examinations were evaluated in two ways. The first method compares the couples of the routes' in one group and uses the Gini-index for characterization of the differences of their comparison. The second method uses Mátrai's algorithm for this task (Mátrai, 2008). It shows the most probable route in the virtual environment on the base of the tested routes. This algorithm gives an adjacency matrix, which can be evaluated manually and with a MathLab function.

At the beginning of the wandering, the VE is divided, and during the tour, the coordinates of those places are stored, which were wandered by the tester. Every route is stored as a sequence of coordinates. The edges of the routes are calculated from these coordinates. The routes, represented by the edges between the coordinates, are compared in couples. If an edge is present in both of the routes, an edge count will be incremented. This computation gives the following two quotients (Eq. 1), that contains the collective edge count and the number of the edges on each route. These quotients aren't equivalent and both of them will be stored, so the computation doesn't need to be run twice with the same routes.

The quotients of the compared routes are

$$y_{12} = \frac{\text{common edge count}}{\text{edge number of the first route}}; \qquad y_{21} = \frac{\text{common edge count}}{\text{edge number of the second route}} \tag{1}$$

As we examine the difference between the routes, we use the following differential quotients:

$$d_{21} = 1 - y_{21}; \qquad d_{12} = 1 - y_{12}; \tag{2}$$

The algorithm compares every route to very other route. Two embedded loops are defined in the code and the inner loop starts from the actual value of the outer one. With this method a computation won't run twice, with the same routes.

At the end of comparing the loops, the dispersion of the stored quotients will be characterized with the Gini coefficient, the formula for which is given as

$$G = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} d_{ij}}{n(n-1)}; i \neq j \tag{3}$$

The second way to evaluate the routes is Matrai's algorithm. It also uses the edges of the routes during the evaluation and represents an adjacency matrix, in size of the VE's divisions. The rows and columns of the matrix will be the vertices of the route. In the beginning, all the values of the matrix are 0. As the algorithm iterates through the routes, at the starting and finishing vertices of the edges, the current value of the matrix will be incremented. When the iteration finished, all of the values of the matrix will be divided by the sum of the rows. With this step, the outgoing edges' values will be between 0 and 1, that's why we call this route the most probable route, and it shows the significant route of the VE. To determine this route, we have to make the matrix negative, and use a shortest path algorithm, which works with negative values too.

5. RESULTS

In the present experiment we examined only left handedness and right handedness, as well as the two groups of users, who used VEs often and who were novice users. This was, however only a pilot study, and it can be extended for the examination of any other study group, e.g. for the comparison of intellectually disabled persons with average users or users who have difficulties in learning, etc. The present results concentrate on the investigation of handedness.

We had only 16 routes from the examinations, which is not enough to make stable conclusions, but these examinations gave interesting results, witch should be examined with a bigger tester base.

At the evaluation of routes in the labyrinth, the most probable routes lead right from the starting point, (Figure 4) and most of them cross the labyrinth. This result is relevant in all of the examined groups.

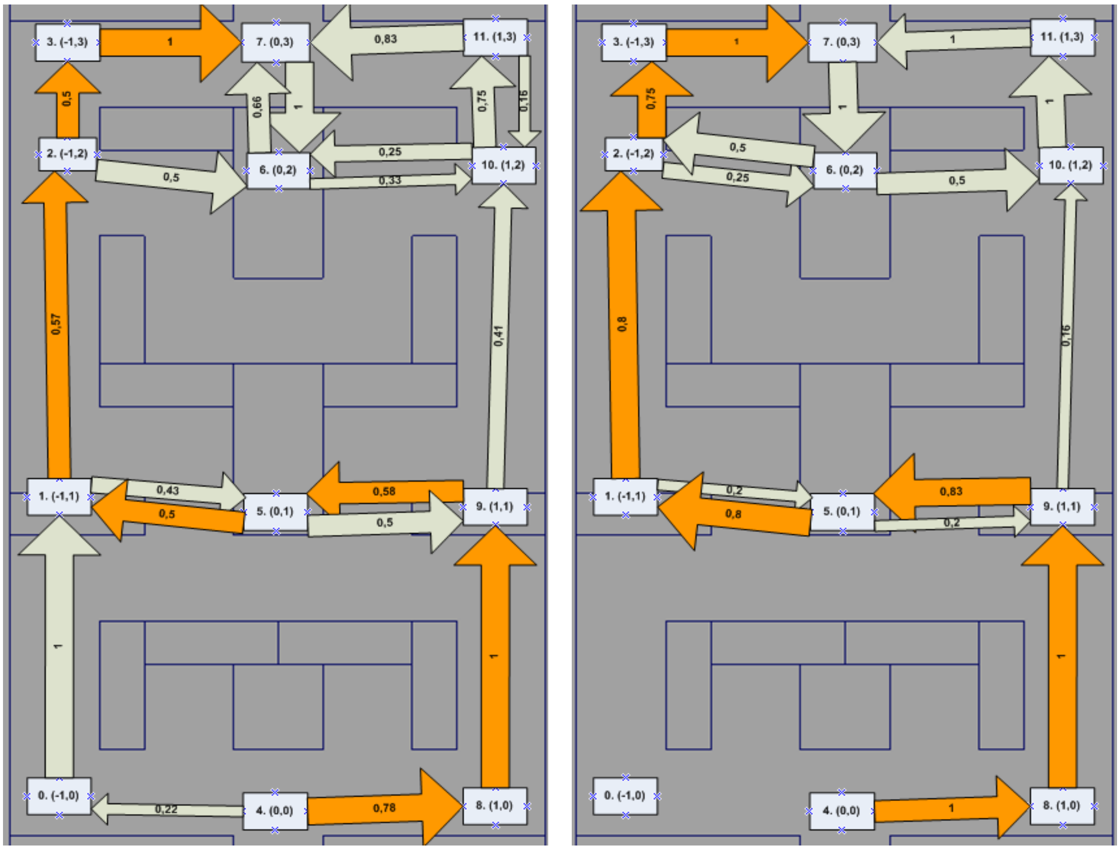

Figure 4: *Most probable routes in the VE Labyrinth.*
Significant routes are marked with yellow.

At the evaluation of the routes by handedness, most of the testers watched the pictures of the VE Gallery in a circle, although this environment is free to wander (Figure 5). The left-handed users wandered it from left to right, and the right handed users from right to left.

These results are confirmed by the probable routes of the VE Store, where the left-handed users wandered from left to right. For the right-handed users it is equalized between the two directions (Figure 6). To conclude these results, we need a bigger tester base.

Evaluating the routes by the novice and experienced groups, we found that the significant routes in the store and gallery are almost equally divided between the two groups (Figure 7). Only the labyrinth shows divergence, because the experienced users discovered the labyrinth.

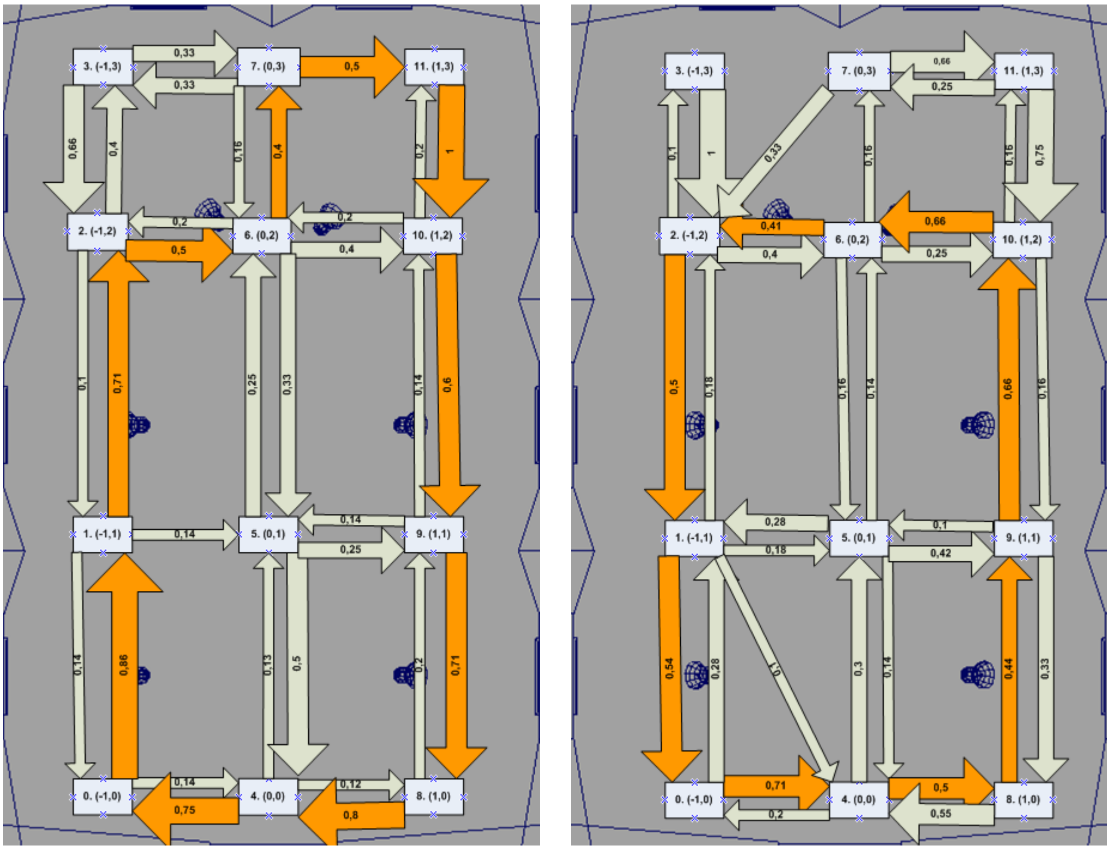

Figure 5: *Most probable routes in the VE Gallery.*
Significant routes are marked with yellow.

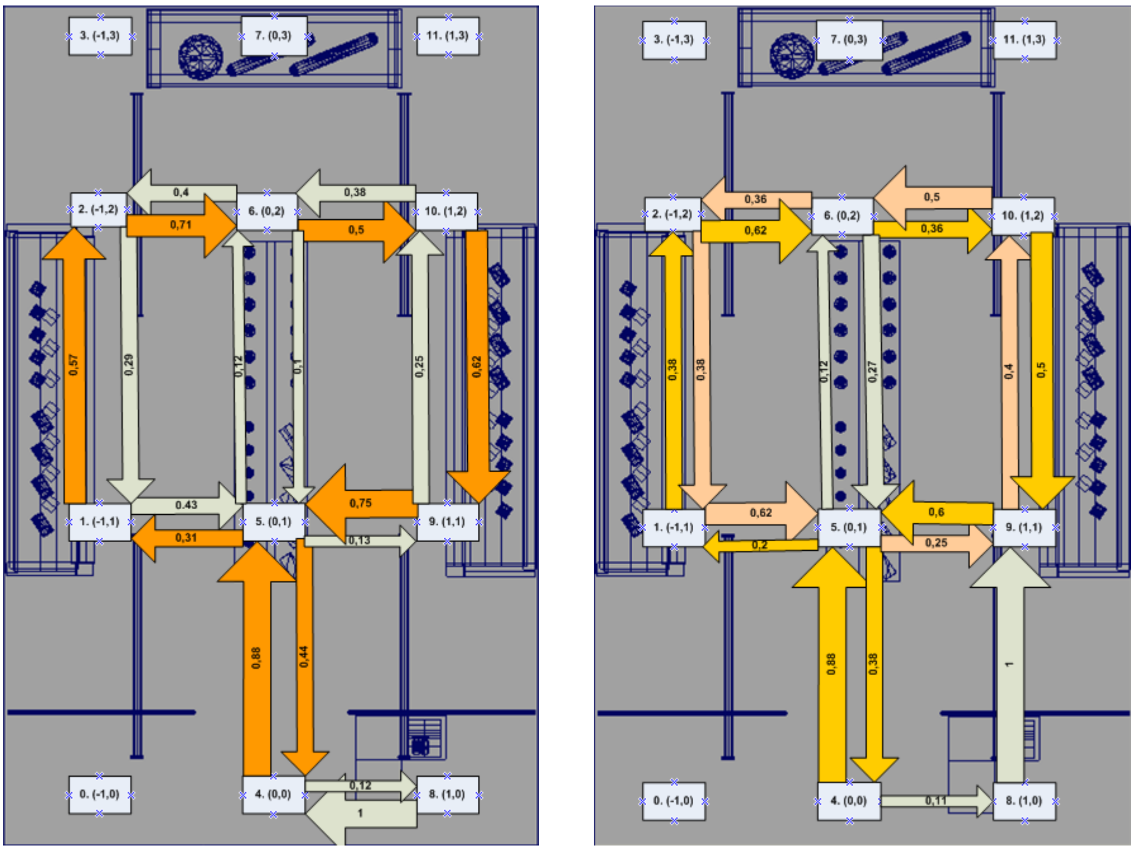

Figure 6: *Most probable routes in the VE Store.*
Significant routes are marked with yellow.

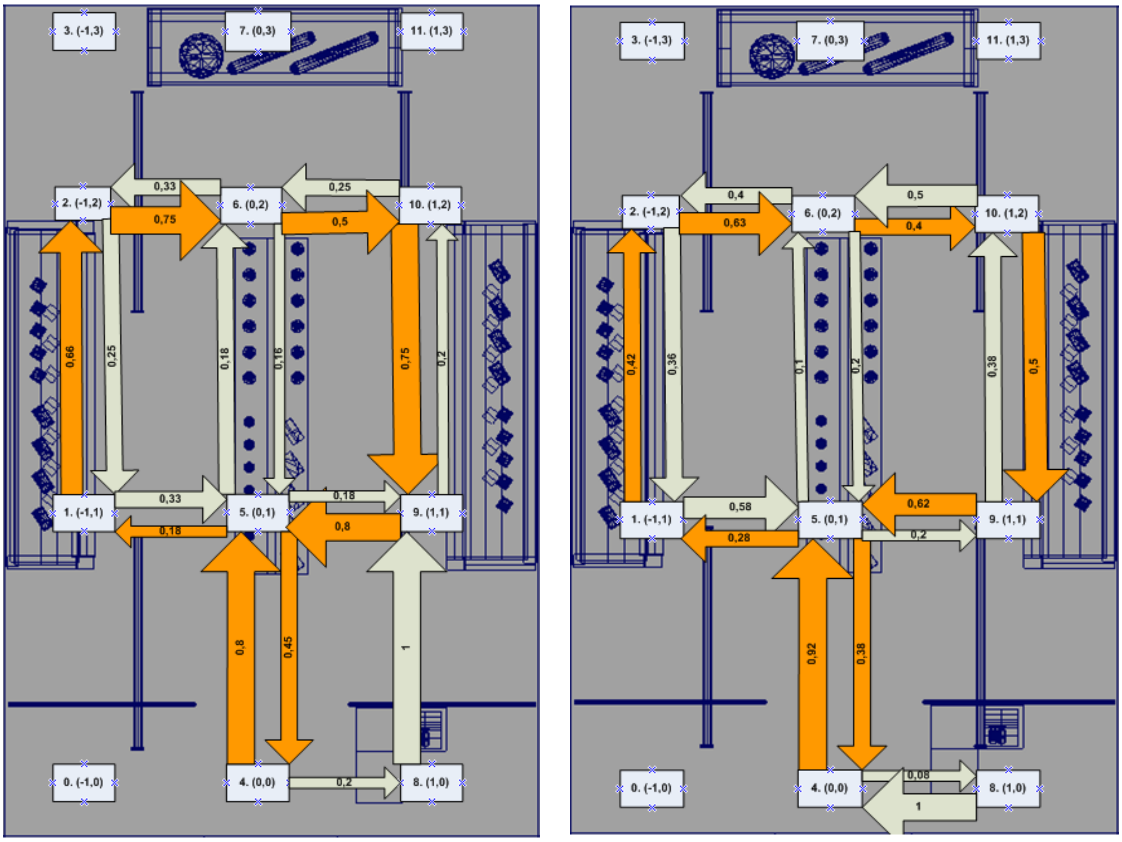

Figure 7. *Most probable routes in the VE Store between the novice and experienced groups. Significant routes are marked with yellow.*

6. SUMMARY

Three virtual environments (VE): a VR gallery, a VR store and a VR labyrinth were developed for the investigation of the users' routes. 16 observers used this test software in 4 groups: left-handed, right-handed, people who play often with VR games and people who play with VR games rarely or never. The result of the pilot test is positive, we found difference between the left and right handed users' routes, but more data are needed to prove this conception.

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Effect of game speed and surface perturbations on postural control in a virtual environment

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http://ljmu.ac.uk/rises/performance/80199.htm

ABSTRACT

The aim of this study was to describe the relationship between performance and difficulty set by altering game velocity and surface perturbations in a virtual game environment. Performance deteriorates as game difficulty increases when changing game velocity and surface perturbations. Adjustment of both game velocity and the introduction of surface perturbations independently appear to be simple and effective methods of customising task difficulty as a function of patients' motor ability during rehabilitation.

1. INTRODUCTION

Virtual rehabilitation provides the three cornerstones of motor learning which are repetitive practice, feedback about performance, and motivation to endure practice. A wide variety of methods have been used to apply virtual reality technology to enhance motor learning in people with disabilities (Holden, 2005) including assessment and rehabilitation in stroke and cerebral palsy (CP) with a specific focus on posture and balance.

Both CP and stroke are disorders which disrupt motor performance, including impaired muscle control and selectivity. Kuttuva *et al.* (2006) suggested that virtual reality can address some of the needs of stroke patients. It does this through the intensity and duration of training it can provide, through improved motivation, objective performance measures, and the ability to monitor patients at a distance. The primary abnormalities characterising CP include loss of selective muscle control, muscle imbalance and deficient equilibrium reactions. The manifestation of these abnormalities around the lower back and pelvis can be related to the concept of core stability. In spite of the primary damage to the central nervous system, motor function can be improved by controlled exercises based on the concept of neuroplasticity and this gives rise to various training methods in CP aimed at improving core stability. Several methods exist for quantifying core stability including strength measurement and electromyography of lumbopelvic muscles but it is unclear if improved core stability is associated with increased or reduced activity of muscles (Barton *et al.*, 2006). Rather than focusing on the muscular control underlying core stability, virtual environments driven by movement of the core may be used to measure and potentially improve core stability. Within the process of movement re-training, the improvement of core stability is a pre-condition of well functioning extremities and so an improvement of general movement function is expected to occur (Barton *et al.*, 2006).

Control of the core was quantified by Barton *et al.* (2006) using a virtual reality game in which a magic carpet was flown through a virtual world being driven by movement of the pelvis towards balloons appearing at random positions. It was a long term anticipation that by applying the benefits of virtual reality alongside a moving CAREN platform there would be improvements in core and peripheral stability, leading to better balance in cerebral palsy. One participant with asymmetrical CP diplegia along with one healthy subject were tested, who played a virtual reality game driven by visual and somatosensory feedback in the form of riding a magic carpet through a virtual world with the overall task of bursting balloons appearing at random positions. The game was driven by co-ordinated translation and tilt of the pelvis. It was found that the CP patient only burst around 40% whilst the healthy subject burst 100% regularly. The game's set level of difficulty was probably too low for the healthy person and too high for a patient with reduced core control due to cerebral palsy. Motivation to endure the game may come in way of finding the "sweet spot" which could be described as the level of difficulty which is not too hard to make someone give-up, but not too easy to make the person

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lose interest. Increasing game velocity is deemed to increase difficulty due to the phenomenon of speed-accuracy trade-off (Utley and Astill, 2008). It may also be plausible to combine the idea of altering game velocity with that of support surface perturbations particularly if these can be directed to affect the specific movements of the pelvis (tilt and rotation) which drive the game. Burtner *et al.* (1998) found that specific groups of muscles get activated in response to controlled movement of the supporting surface. They used a research paradigm using a moveable platform system to test stance balance control in adults and children. By displacing the platform unexpectedly, stance balance was perturbed in the individuals and resultant muscle responses to recover an upright posture were recorded. Adults were found to compensate for forward sway following unexpected backward platform movement by activating multiple muscles together as a functional unit.

Human balance and postural research has frequently used translational and rotational perturbations of the surface on which a person stands. Apparatus used to rotate the surface are usually constructed so their axes of rotation are constrained to run close to the platform surface resulting in non-specific movement perturbations acting on the whole body. The CAREN system (MOTEK, Amsterdam, The Netherlands) based on a Stewart platform consists of a 2m diameter platform that can be moved by six computer driven hydraulic actuators in six degrees of freedom (Fig.1) (Barton *et al.*, 2006). The CAREN platform has great potential as a research tool for postural research as it works in six degrees of freedom, independently rotating via pitch, yaw and roll, and translating via surge, sway and heave (Vanrenterghem *et al.*, 2005) because such full control of movement can be used to direct perturbations to specific body segments. An algorithm developed by Barton *et al.* (2006) was used in a number of recent studies which employed joint specific proprioceptive perturbations of balance by rotating the platform around a specific joint axis enabling the investigation of joint specific balance correction strategies beyond the conventional ankle and hip strategies (Barton *et al.*, 2005). The systematically determined kinematic response characteristics of the CAREN platform by Lees *et al.* (2007) lead to a conclusion that the CAREN system is an appropriate device for postural and balance research. Current research with this platform also includes a study by Foster *et al.* (2008) which investigates movement co-ordination of the pelvis in a virtual game environment. Here the CAREN system was used in conjunction with virtual reality to evaluate core control and pre-established patterns of co-ordination within the game environment.

The aim of this study was to describe the relationship between performance and difficulty set by altering game velocity and surface perturbations in a virtual environment.

Figure 1. *The CAREN platform (MOTEK, Amsterdam, The Netherlands) can generate targeted movement perturbations which can be used to control game difficulty.*

2. SUBJECTS/MATERIALS AND METHODS

Four healthy male volunteers (age: 19-23 years) were trained to play the magic carpet game, allowing them to adapt to the game environment and learn the control schemes at a standard default level of game speed (40 m/s) and without surface perturbation. A virtual reality game used by both Barton *et al.* (2006) and Foster *et al.* (2008) was employed where the task is to fly a magic carpet through a virtual world bursting balloons appearing in seemingly random positions. The subject controls the game by moving the pelvis in a way as to move the magic carpet both vertically and horizontally driven by simultaneous pelvic tilt and rotation. Visual feedback on the subject's movement was generated by the CAREN system (MOTEK, Amsterdam, The Netherlands).

Three dimensional orientation of the pelvis was determined by real-time tracking and recording of the movement of 3 markers attached to the PSISs and the sacrum using 8 Vicon 612 cameras (Fig. 2). Transverse plane rotation and sagittal plane tilt of the pelvis was driving the carpet sideways and vertically respectively

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towards balloons appearing at random positions. Where the balloons appear within the game is pre-determined in their trajectory but appear random to the participants.

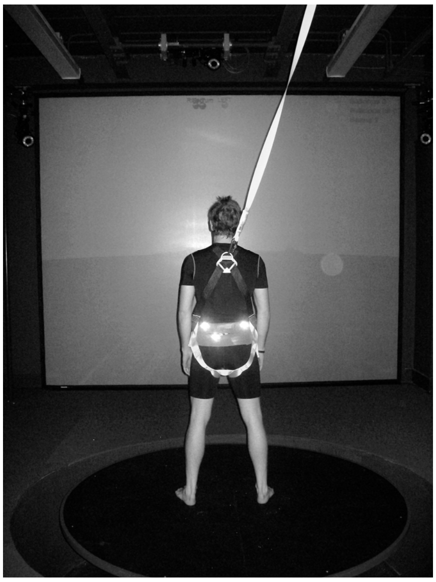

Figure 2. *The participant is standing on the CAREN platform with a cluster of reflective markers attached to the pelvis; driving the game, and flying the magic carpet through the virtual world. The platform acts as a stable base when carpet velocity is increased and can introduce surface perturbations whilst the subject endeavours to burst balloons.*

The participants undertook a number of trials over a pre-determined set of trajectories (Fig. 3), potentially bursting up to 225 balloons based on a 200 displacement stimuli for each trial. Difficulty settings for the game were defined by carpet velocity at 30 m/s, 40 m/s, 50 m/s, 60 m/s, 70 m/s and default gain settings (Tab. 1). The participant progressed to the next velocity when regularly bursting at least 7 out of 9 balloons. If the subject was unable to achieve this, they ran through a full set of the trajectories before moving up a level. One of the 8 pre-determined trajectories was selected for analysis which ensured the subject was tilting and rotating the pelvis at the same time, so as the participant completes a multiple task controlling two degrees of freedom of the pelvis simultaneously. The averages of all instantaneous distance curves from the carpet to the balloon in the coronal plane were plotted together with ± standard deviation (SD) indicating variability of performance, for all five velocities. The measure of performance was quantified by the area under the distance curves normalised to the duration of approach. Additionally, the maximum standard deviation (SD_{max}) was used as a measure of performance variability.

Following this set of data collection participants were brought back into the laboratory to investigate the relationship between performance and platform movements. The same subjects firstly undertook a full set of 225 trajectories at default gain levels and at a carpet velocity of 40 m/s, to re-familiarise themselves with the game.

The CAREN platform moves in six degrees of freedom allowing it to rotate (pitch, yaw, roll) and translate (surge, sway, heave). The subjects undertook three levels of the magic carpet game with default gain settings and carpet speed at 40m/s, but with the platform moving randomly driven by a series of overlapping sinusoidal waves to define carpet movement in a specific degree of freedom. The three levels were defined as Surge, Yaw, and SurgeYaw (combining both movement in the Surge and Yaw levels), moving the carpet so as to force sagittal plane tilt (influenced by platform Surge) and transverse plane rotation of the pelvis (influenced by platform Yaw), henceforth disrupting the task of driving the carpet. The averages of all instantaneous distance curves from the carpet to the balloon in the coronal plane were again plotted together with ± standard deviation (SD) indicating variability of performance, for the three platform movement levels. The measure of performance was again quantified by the area under the distance curves normalised to the duration of approach. The maximum standard deviation (SD_{max}) was also used again as a measure of performance variability.

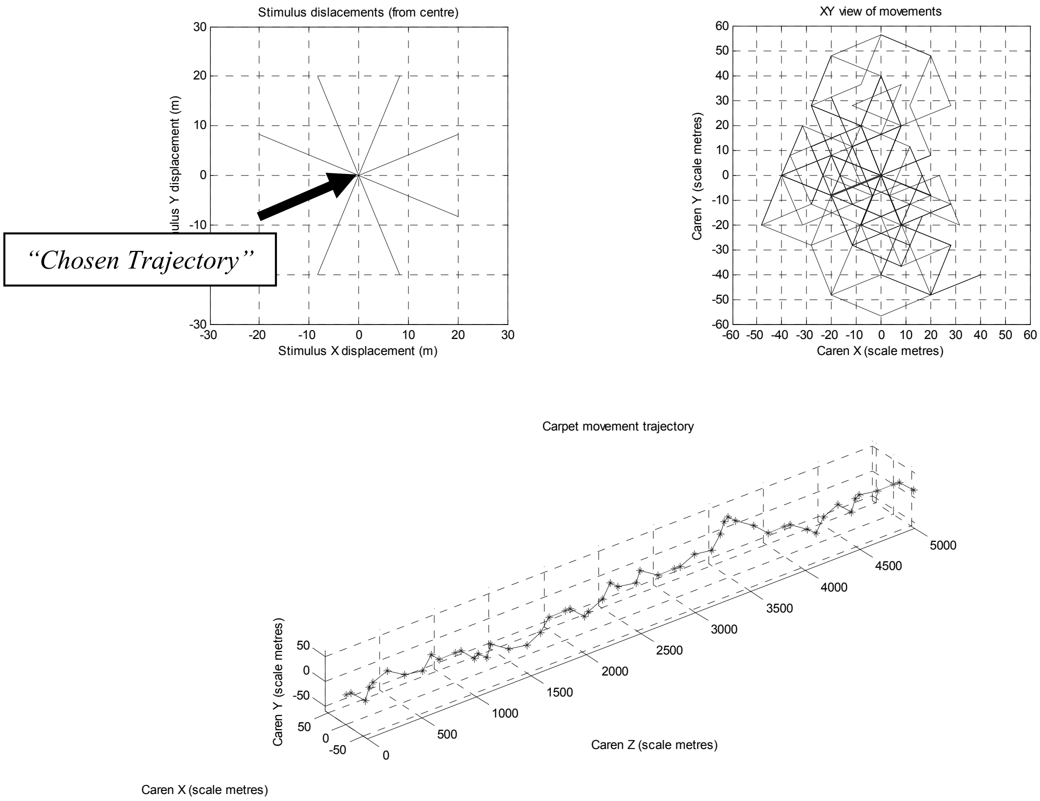

Figure 3. *The top-left plot shows an X-Y plot of the eight trajectories. The top-right plot shows the X and Y range of 200 trajectories (25 x 8) presented in blocks of eight in random order within each block. The 3D plot shows an isometric view of the first five sets of eight trajectories plotted end to end. The chosen trajectory incorporates both movements of the pelvis involved with the control scheme: pelvic tilt and rotation.*

Table 1. *Default Magic Carpet gain settings. Gain was changed proportionally to velocity.*

Level	Velocity (m/s)	X gain (m/s/deg)	Y gain (m/s/deg)
1	30	1	0.5
2	40	1.33	0.67
3	50	1.66	0.84
4	60	2	1
5	70	2.33	1.17

3. RESULTS

Figure 4(a-f) represents the averaged results for all subjects at the specified trajectory. Graphs (a-e) show that there is a lack of movement towards the target at the beginning of the specific trajectory (first 0.5 s) and the linearity of the curves after this initial decision making increases as carpet velocity increases. The variability (SD) increases gradually as carpet velocity increases [Fig. 1(a-e)], and its maximum occurs around the point of transition from decision making to pelvic movement. The area under the curves also increases as carpet speed increases [Fig. 1(a-e)]. These results for normalised areas under the curves, and variability (SD_{max}) are shown graphically in figure 1(f).

A one-way repeated measures ANOVA test showed significant differences in the area under the curves, ($F_{2.164,\ 6.491} = 11.832$, $P < 0.05$), and for the variability of movement (represented by maximum standard deviation; $F_{2.288,\ 6.865} = 11.735$, $P < 0.05$) for all subjects. Post-hoc analysis showed that normalised area under the curve at 50 m/s was significantly greater than that at 30 m/s and that the normalised area under the curve at 60 m/s was significantly greater than that at 30 m/s and 40 m/s. Post-hoc analysis also showed that the variability for 70 m/s was significantly greater than at velocities 30 m/s, 40 m/s and 50 m/s.

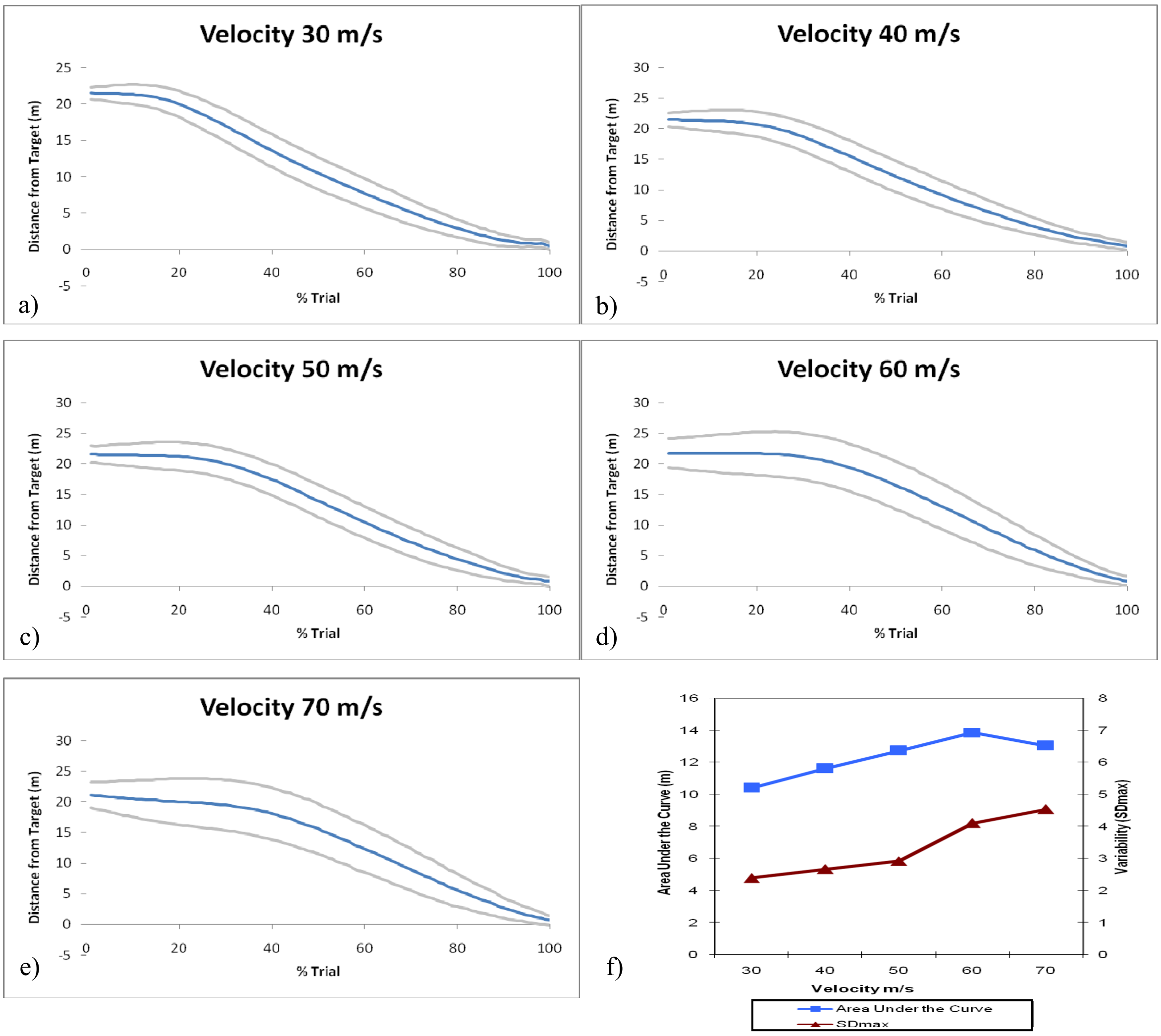

Figure 4. *(a-e) Distance – time graphs for all subjects at all test velocities. (f) Normalised area under the curve and variability results as a function of game velocity.*

Figure 5(a-f) represents the averaged results for all subjects at the specified trajectory under the four conditions of no support perturbation (NoSP), Surge, Yaw, and combined SurgeYaw. Graphs (a-e) again show similar characteristics to those in figure 4b, when the same carpet velocity was used (40 m/s). The variability (SD) curves for all surface perturbation test graphs are similar. Differences do appear however at the start of the approach, where variability is larger in Surge and Yaw than NoSP and even more so in Surge Yaw.

A one-way repeated measures ANOVA test showed no significant differences in the area under the curves, ($F_{1.557,\ 4.672} = 1.018$, $P > 0.05$), and for the variability of movement represented by maximum standard deviation ($F_{1.622,\ 4.866} = 0.333$, $P > 0.05$) for all subjects.

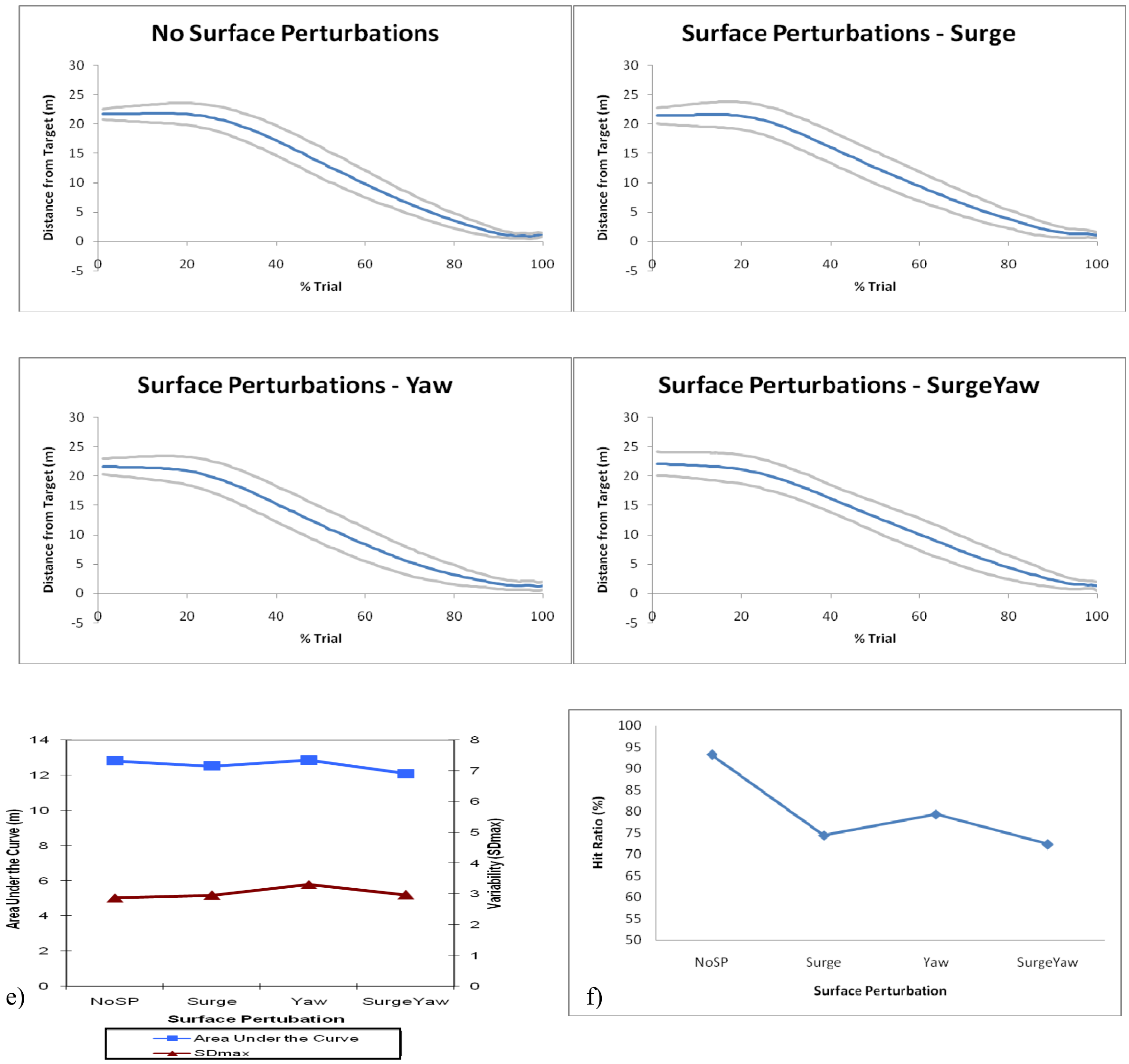

Figure 5. *(a-d) Distance – time graphs for all subjects at all test surface perturbations "No Surface Perturbations" (NoSP), "Surge", "Yaw" and "SurgeYaw". (e) Normalised area under the curve and variability results as a function of surface perturbations. (f) Average balloon hit percentages for all subjects across all test surface perturbations.*

Although no significant differences were found between performance measures and type of surface perturbation, when looking at a hit percentage graph [Fig. 5(f)] it is clear that the hit percentage decreased when surface perturbations were introduced. A one-way repeated measures ANOVA test showed significant differences in hit percentages, ($F_{1.526,\,4.578} = 8.127$, $P < 0.05$) across all subjects. Post hoc analysis showed that balloon hit ratios at Surge, Yaw, and SurgeYaw surface perturbation tests were all individually significantly different from No Surface Perturbations (NoSP). Post hoc analysis also showed that there were no significant differences between types of surface perturbation.

4. DISCUSSION

Initially there is no movement towards the target and this represents a phase of decision making as to how to move the pelvis in order to drive the magic carpet towards the balloon. Linearity of the curve after the initial decision making period increases with velocity, showing that there is a need for a more direct approach to the balloon at higher game velocities. The maximum point of variability appears to occur at the beginning of pelvic movement, where the subject makes initial adjustments. Taking the above into consideration we could divide the trajectory into three sections of decision making, initial adjustments, and minor corrections.

Statistically as carpet velocity is increased, performance (defined by area under the curves and maximum variability) deteriorates. We can discover a threshold of velocity above which the game becomes more difficult. Post hoc analysis shows that 30 m/s, 40 m/s, and 50 m/s levels produce significantly lower results than those at 60 m/s and 70 m/s levels. However, 30 m/s, 40 m/s, and 50 m/s levels are not significantly different from each other and neither are 60 m/s and 70 m/s levels. We can therefore say that a difficulty threshold lies between 50 m/s and 60 m/s levels.

A limitation of the velocity results as an indication of performance is that of the discovered decision making phase. Since the decision phase appears to be relatively constant at all carpet velocities, then the area under the graph results will naturally increase, due to the longer block taken up by the decision making phase.

When looking at graphs representing difficulty changes by introducing surface perturbations, the trajectory can again be divided into the identified three sections previously described. However, surface perturbation test graphs all show similar curves, with similar areas under the graphs, which was backed up by the statistical tests showing no significant differences in different types of surface perturbation. We can however see slight differences at the start and end of the trajectories when looking at variability. The variability is low for NoSP, suggesting a smooth exit from the previous trajectory, whilst for individual surface perturbations Surge and Yaw, the variability is slightly larger. This change is more noticeable in SurgeYaw when a dual surface perturbation is introduced, suggesting it is more difficult to target the following balloon at this surface perturbation level. It may also be fair to say that SurgeYaw variability is changing throughout the movement, represented by a double bump of the SD range in the initial adjustments phase.

Although it appears that the game does not become more difficult when introducing surface perturbations, as shown when using area under curves and variability as performance measures; if balloon hit ratio is taken into consideration, results differ. Using hit ratio as a performance measure showed that the game became significantly more difficult as average scores of 95% dropped by around 20%. It is therefore fair to say that the introduction of surface perturbations does make the game more difficult. Furthermore, post hoc analysis showed that it does not matter what type of surface perturbation was introduced as there were no significant differences between types of surface perturbation tests.

5. CONCLUSIONS

Game velocity appears to be a simple and effective means of increasing difficulty of the game when measuring core control and customising task difficulty as a function of patients' motor ability during rehabilitation. Such manipulation of difficulty may be necessary to more accurately quantify movement performance of patients with a widely ranging level of motor abilities, while maintaining their motivation during the protocol. Introducing surface perturbations may also be used in a similar way, but only if hit ratios of balloons burst are used as a performance measure and only when the game velocity is set to 40 m/s; further research into a relationship between game velocity and surface perturbations may be useful. Further research into a relationship between surface perturbations introduced and control mechanisms, such as pelvic tilt and rotation gain settings may also be necessary in order to establish whether area under the curves and variability can be used as performance measures when introducing surface perturbations.

The results gained from healthy participants establish baseline data which may be used as a reference for non-healthy participants such as those with CP. Further testing must be carried out on non-healthy subjects applying what has been learned from this study in order to develop appropriate game settings, which can be used in a rehabilitation programme, in order to evaluate and improve core control.

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Towards a platform of alternative and adaptive interactive systems for idiosyncratic special needs

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ABSTRACT

Eight participatory workshops were created as a hybrid situation wherein physical and virtual environments were designed to investigate responses of attendees when empowered by non-invasive sensor technology to interactively control responsive multimedia through motion. 144 disabled children and adults attended with caregivers and helpers. Targeted were fun experiences, social interactions, and recognised achievements. Evident was that the majority of disabled attendees joyfully, freely and creatively self-articulated and playfully interacted. However, traditional caregiver role in such situations is questioned following observations from the workshops. Specific design issues, targeted effect-goals, and attendee responses are reported in the paper. Conclusions reflect how such hybrid situations can offer opportunities to assess the dynamic relationships between technical set-ups and related human responses. Strategies are proposed towards future inter/multidisciplinary open research platforms to more fully examine potentials of motion-sensitive environments for this segment of society.

1. INTRODUCTION

The “Ao Alcance de Todos - Within Everyone’s Reach” festival was hosted at Casa da Música, Porto, Portugal in April 2008. Included was the ‘SoundScapes Virtual Interactive Space: ArtAbilitation Workshop 2’ which consisted of eight one hour workshops. They were created as a hybrid situation wherein physical and virtual environments were designed to investigate responses of attendees when empowered by non-invasive sensor technology to interactively control responsive multimedia through motion. The situation is referred to as virtual interactive space (VIS) (Brooks 1999) wherein the SoundScapes motion-sensitive environment (MSE) enables interactive control of responsive multimedia. 144 disabled children and adults attended with caregivers. Additionally, a symposium for professionals was hosted immediately following the 8 workshops for approximately 35 professionals (international, national, regional, and local // social workers, psychologists, researchers, teachers, and students …) - many of whom had attended the workshops.

The festival was a week of publicly attended performance art events, workshops, and talks that highlighted the potentials from utilising technology as an alternative means of expression for disabled people. Third party holistic in-depth enquiry was undertaken with a research report imminent. The workshop series that is the focus of this paper was an element of the festival and as such contributes to the future report, therefore, the focus of this paper is restricted to the specific design, the associated effect-goals, and the resultant attendee responses observed in the workshop sessions wherefrom findings have been drawn.

1.1 Attendees and organisation

Workshop attendees were from regional special needs institutes, schools and hospitals. All marketing, scheduling and organisation were administered by the educational services in Casa da Música, Porto, Portugal. This was the second ArtAbilitation workshop following a similar event at Casa da Música in April 2007 (see Petersson & Brooks 2007).

2. DESIGN

The workshops were created in a room of approximate dimension, 238 square meters floor area, 20 meters high (approx). A plan of the layout is illustrated in figure 1. The floor was black. A mirror-wall is on the right-hand side after the entrance. Large speaker systems were positioned to maximise vibration of the wooden floor. Truss box sections and black theatrical curtains were used to divide the room into five specific areas. Attendees experienced subsequent areas with each next environment hidden from view until a curtain was opened from the preceding area. This was to minimise attendee distraction. Hidden video cameras in accord with ethical stipulations were arranged throughout to record the attendee interactions. A researcher interview area was additionally established with suitable lighting and microphone for manual video camera recording.

Each area was designed with a specific attendee experience (goal-effect) in mind, and these are outlined in the text. Overall goals included generally stimulating, empowering and challenging the attendees towards experiencing self-driven fun, improved temporal social interactions, and a self-recognized sense of achievement. Physical movement was the input/control means. Doors were closed when the attendees arrived. All removed their shoes so that the vibrations resulting from the sound manipulations could be experienced via the wooden floor. After an introduction, including translation/signing, doors were opened for attendees to enter. Author, translator and technical crew combined in guiding the attendees in the workshop.

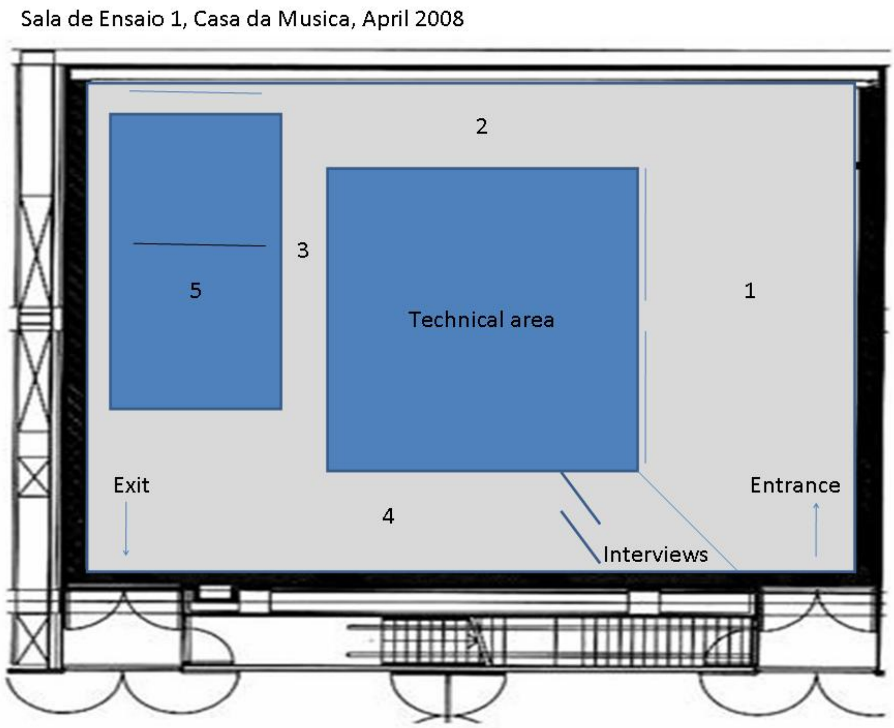


Figure 1. *Plan view of workshop area.*

2.1 Area 1

A motion-sensitive environment was created as the first area. The area was accessed via a large double door 'Entrance' in Figure 1. A picture taken from the entrance is presented in figure 2. There was minimal lighting and upon first viewing without attendees being present to activate the motion sensors there was no image projections, hence the area was dark. On entering, the attendees paused as the author gave a demonstration of how physical articulation of one's own body within designated areas, or movement of mobile interactive structures (i.e. 'enhanced' window blinds) (Brooks 2005) could be explored to create and manipulate music, images and vibrations. Microphones were centrally mounted above attendee heads to capture utterances and other sonic attributes generated in the area and this was also demonstrated. Four 'SoundScapes programmed' Roland SP555 D-beam sampler units were used to manipulate the sonic content.

Each sensor device was mounted and secured on a music stand so as to be flexible to adapt from vertical to horizontal orientation with 360 degree directionality available according to the individual preferences. Dynamic pads enabled the triggering of preferred sounds. An onboard microphone input socket made it possible to convert attendee utterances into samples and effects for playback. Output from each of the sound modules was mapped to visualisations on a PC. In this way attendees were empowered, to directly affect projected images (figure 2). In this way, the multimedia attributes of the area were dependent on input from the attendee, as otherwise - without movement or utterances there were no sounds, images or vibrations. The mirrored wall on the right of the entrance cannot be seen in figure 2 but this was consciously utilised as an environment design feature.

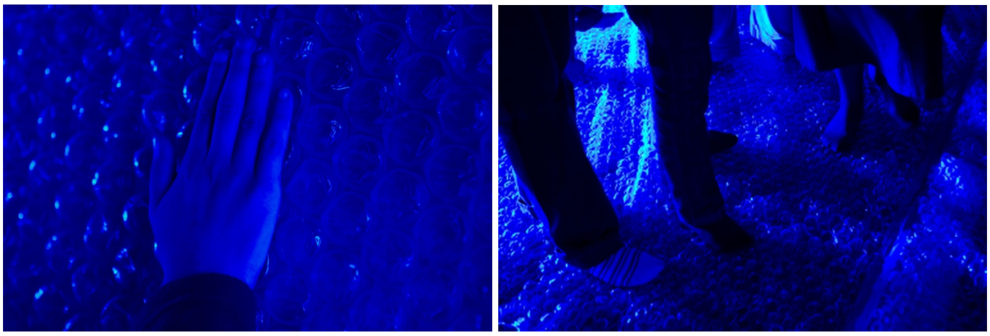
Figure 2. *Entrance view of area 1 – approximately 14 meters length x 6 meters wide. Two 4x4 meter back projected screens dominate in the figure by showing examples of the interactive images manipulated via motion. Two of the mobile interactive structures are located in-between and in front of the screens.*

A goal of the first area was to promote a sense of independence; a feeling of empowerment; and the sensation of control over own experience for the disabled attendees. The guides assisted by improvising interaction so as to optimise attendee experiences, and, where appropriate, disabled individuals were encouraged to explore without their caregiver. This was based upon prior observations where caregivers had been interpreted as unintentionally preventing the disabled person in their charge having an optimal experience through curtailing activities in order to ensure that they did not do any damage to equipment or themselves. However, this complex issue is beyond the scope of this paper to address other than reporting what was witnessed.

Figures 3, 4 & 5. *Image manipulation interactively controlled by disabled attendees in area 1.*

2.2 Area 2

A black heavy theatre curtain divided areas 1 and 2. Large 'bubble wrap' (figure 6 & 7) was used to cover the floor and walls. This design was based upon prior experience of how disabled people were observed to enjoy the feel underfoot and of squeezing and exploding the bubbles by hand. Blue LED lighting was used to replicate a swimming pool ambience which is acknowledged in the field of disability as mostly pleasing and positively familiar to attendees. Reverse-phase microphones were used to capture utterances and sounds from interactions, i.e. bubble wrap explosions, articulated utterances/clapping, and individual/group jumping and stamping. The microphone setup minimized sonic feedback due to the limited area size (see figure 1). A sound effect was used to enhance the sonic experience of this area. A goal of this area was to build upon attendee experience gained from area 1 so as to further free them of any preconceived rules or expectations in order for them to freely express themselves as they wanted. The design at the same time promoted physical activity, social interaction and above all "fun" through empowered ludic engagement.



Figures 6 & 7. *Large bubble wrap fixed to walls and floors in area 2 for individual or group exploration.*

2.3 Area 3

Area 3 (figure 8) was designed as a simple, empty and narrow passageway that was lined with black curtains on either side. It was sized so that each disabled person was encouraged to traverse alone without support (unless required) towards areas 4 and 5. The goal of this transitional area was to evoke a feeling of identity, confidence and self-esteem following experiences gained from the earlier areas.

Figures 8 & 9. [Left] **'***area 3' - the narrow curtained passageway;* [Right] *'area 4' – chill out + exhibition.*

1.6 Area 4

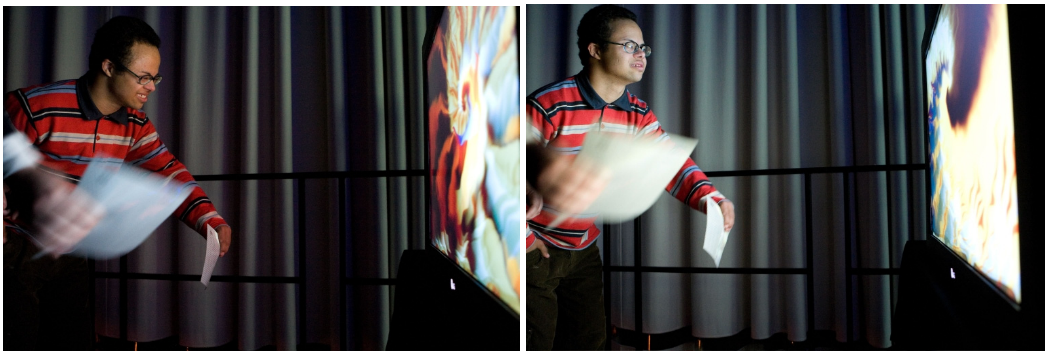
Area 4 (figure 9) was multi-functional with colourful bean bags. A goal of this area was to offer an integrated 'chill-out' zone/preparation space/… and exhibition place where achievements and experiences could be shared. Here, the next area (5) was introduced and questions were answered. Two wall spaces that bounded the 'Exit' (figure 1) were used as an exhibition place for digital paintings that the attendees created in area 5. The design was that attendees, where applicable, mounted their own picture on the wall.

1.7 Area 5

Figures 10, 11, & 12. *area 5 – set-up* [Left] *with printer behind:* [Centre & Right] - *Two female attendees on the platform exemplified how the control of interactive media through gesture can promote social interaction (Vygotsky 1978); peer learning (e.g. Rogoff 1990), and scaffolding (e.g. Wood et al. 1976).*

Prior areas were designed to prepare attendees for this final motion-sensitive environment which was realised as a multisensory platform/projection area (figure 10). Here, attendees received responsive multimodal stimulation as a result of their gestures. A black curtain divided areas 4 and 5. Upon entering area 5 attendees climbed onto a wooden platform about one meter high (wheelchairs were carried). Low frequency sub-woofers were mounted on the underside of the platform floor to maximize vibrations. Two SoundScapes programmed Roland SP555 units were positioned at an angle pointing toward where attendees were guided to stand or sit (figures 11 & 12). The movement-to-sound interaction was within two 3D infrared sensor spaces that responded at distance to a square reflective artefact (figures 13 & 14). A 42″ monitor was positioned for 'performer' monitoring of the manipulated visualisations created for the adaptive PC software Winamp[1]. A webcam was positioned on the monitor to capture attendee motion for image processing. Four meters behind the monitor a projected image on white curtain gave visual information feedback of how the attendee body movement and reflective artefact were dynamically painting (figures 11 & 12). An algorithm titled 'bodypaint'[2] created in the software programme Eyesweb[3] was used for the dynamic painting (Brooks & Hasselblad 2004). To create a digital painting print in real-time involved an 'in-action' screen capture of attendee interaction which was then transferred to the image editing software IfranView[4] to selectively extract, crop, resample and then print - all while the person was 'painting' as then the print was ready to hand to him or her as they descended from the wooden platform. This was given to the attendee so that he or she could mount in the exhibition area (figure 9) and then later keep as a souvenir to recall the experience.

A goal of this area targeted the attendee to associate the square reflective artefact movement to the change of sound, vibration and image. This was conceptualised as possibly being a suitable tool for therapists to work with for eye-to-hand coordination, concentration or awareness exercises.



Figures 13 & 14. *Using the square reflective artefact in hand to play and perform with sound and images.*

3. COMMENTS AND OBSERVATIONS

The holistic design was reverse engineered from area 5, where a multisensory platform environment acted as the conduit between attendees and the multisensory feedback. In this area attendees' self-articulation was designed to be at a more individual level, and guidance, where required, was at a more intense level. Previous areas (1-4) were preparation areas where each person, as a part of a group, progressed through the areas whilst being encouraged to freely express individually or collectively. Targeted from the prior areas was a progressively free mind-set towards creative expression and playful interaction without any rules or expectations. The prior areas also targeted to afford a sense of identity for the disabled attendee such that they perceived appropriate actions and discovered a sense of agency, and hence self-empowerment through 'actively self-doing'. This positive aspect was balanced by certain caregivers who were observed to curtail their charge in line with what Petersson (2006) calls a problematic 'power culture' in education. It was as if the caregiver, upon realising their disabled charge empowered, lost their umbilical contact to the workshop. In other words, observations were that they were lost without having the disabled person in their charge; however, this could also be associated to their knowledge of the person and instructions of their role for the workshop from leaders. It was also observed that other caregivers actively shared the performance space and encouraged interactivity by using the mediating stimuli as a communication aid for attendee articulation.

The mobile structures gave a tangible quality to the interactions in area 1. Some attendees 'played' the installation by moving the various 'enhanced' artefacts which were on wheels. At any time they could position the artefact and then perform in front of it alongside others who were active. The physicality of this interaction seemed pleasing for many of the attendees. Others found (or were guided to) sensor and microphone 'hot spots' so as to contribute to the multimedia collage in a more sedate way. However, it was also confusing when the groups were too big as association from one gesture to a single direct audiovisual feedback could not be easily detected and the active attendee needed to listen carefully if there were many colleagues in the area. The initial demonstration attempted to alleviate this problem by demonstrating the sounds in each active zone. During the actual session guides and caregivers helped attendees in this respect.

Indications of 'non-formal learning' (Petersson 2006) were observed for certain disabled attendees and caregivers as they recognised their control of interactive media through gesture. Disabled attendees, especially in area 5, displayed this phenomenon non-verbally and via their facial expressions, which typically changed from surprise to curiosity, interest, and then exploration with subsequent recognition of associations and continued playful interaction. This can be through the learning curve being negligible due to its direct and immediate causal response to action that complements an attendees' neurological response system i.e. suggested closure of the afferent efferent neural loop (Brooks et al. 2002). Additionally, indications from what was observed suggest that the control of interactive media through gesture promoted social interaction (Vygotsky 1978); peer learning (Rogoff 1990), and scaffolding (Wood et al. 1976) whereby the mediating technology all but 'disappeared' and the responsive content became as an inter-subjective other. Evaluations included exhibited aesthetic resonance (Ellis 1997, Brooks et al. 2002, Petersson 2006, Camuri et al. 2003).

Pride and self-esteem in exhibiting personally achieved paintings was observed (and reported by caregiver). Depending on disability most attendees knew where their painting was mounted in the exhibit and would take the guides to view. Following the cessation of the festival the pictures were sent to the attendees. Some attendees took their paintings home directly from the workshop to show their family and friends. Attending caregivers also received a painting of their participation. Throughout all 8 workshops, and in all 5 areas, joyful laughter was commonplace with many attendees excitedly exclaiming their enjoyment and fun.

4. DISCUSSION AND CONCLUSIONS

The positive responses from attendees, and comments received by attending caregivers and leaders at the closing 'professional symposium' suggest that this type of workshop format, where attendee perception and action is designed for, is opportune to observe an empowered situation. Attendee responses included that personal space was protected or shared; interactions were individually or collectively formed; play was solitary or universal. Attendee communication was also evident in, and between, the constructed spaces which added to the social interaction (Vygotsky 1978); peer learning (Rogoff 1990), and scaffolding (Wood et al. 1976) mentioned in section 3 of this paper. The interpretation that certain of the workshop attending caregivers were possibly being over-protective is acknowledged as purely speculative due to observer's lack of knowledge of the people concerned and limited time of observation.

In the closing symposium attendees stated that despite 'technical trepidation', they wished to access the affordable commercial apparatus used in the workshops. Reflecting this, concluding remarks suggested a funding strategy that would enable such purchases with accompanying staff training programmes alongside funded collaborative partnerships between therapists and digital artists where shared knowledge could be productive. However, in a follow-up to the workshop a communication received from the local Roland representative informed that no institute has purchased a sensor unit. Also, the author's networks of local digital artists working with non-invasive sensors in Porto report no contact from institutes or therapists.

From a research perspective the workshops offered further opportunities to question and evolve the author's ongoing SoundScapes concept and strategy of creating situations that empower participants to non-invasively control 'responsive-multimedia by motion from within a virtual environment. The work to date has involved the creation of a concept that is responsible for patented technical apparatus and method. As a hybrid system it has evolved through 3rd party expert assessment of human responses to use. Refinements have thus been based upon investigating dynamic relationships between the technical and the human systems as well as through questioning the complex network of sub-systems that reside embedded within the situation. However, this has been limited and increased multi/interdisciplinary expert collaborations towards improved developments and understandings of the potentials of motion-sensitive environments are deemed needed.

In line with Eaglestone and Bamidis (2008), a future strategy is proposed as outlined above with a view to augment the field through the creation of a designated open research platform. Such a platform could opportunely address the complex issues involving commensurability in respect of corroborated validity and replicability in this multifarious field of alternative and adaptive interactive systems for idiosyncratic and collective special needs. Supplementing this proposal, is that a network of linked platform nodes could be employed to act as a bridge between the academic researchers, commercial developers, and healthcare professionals so that access to appropriate apparatus, training of use, and suitable systematic and meaningful evaluation methods become available alongside an active sharing of expert knowledge so as to directly support partnered stakeholders such as the future generation of therapists, caregivers and disabled people.

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APPENDIX

Data supplied on workshop attendees

Workshop 1. *School*: E.B.2, 3 Matosinhos
Age: 8-16 years
1 with autism
13 with mental retardation
4 with mental retardation + motor disabilities

Workshop 2. *School*: E.B.2, 3 Santa Marinha
Age: 11-16 years old
20 students - hearing impaired

Workshop 3. *Institution* – CAID
Age: 22-41 years
2 with moderate mental disability
2 with Down Syndrome
2 with moderate mental + severe motor disability
1 with mild motor + moderate mental disability

Workshop 4. *School*: Internato Vítor Fontes
32 students
School: Externato Ana Sullivan
Age: 6-19 years
22 students

Workshop 5. *Hospital*: Psiquiátrico Conde Ferreira
Age: + 30 years
16 with psychiatric mental illness

Workshop 6. *School*: Externato Ana Sullivan
Age: 12 – 19 years
23 students

Workshop 7. *Institution:* Cercigaia
Age: + 14 years
2 with moderate mental retardation + motor disabilities
2 with severe mental retardation + autism
1 with moderate mental retardation
1 with severe mental retardation
9 with moderate mental retardation
1 with cognitive disabilities + hearing impaired
1 with Spina Bifida
1 with Treacher Collins Syndrome + Genetic cardio disease

Institution: Centro de Educação Especial de Penafiel
Age: 4-10 years
15 children hearing impaired

Workshop 8. *Institution*: APPACDM
Age: 19-51 years
7 with severe mental retardation
3 with moderate mental retardation

Virtual reality and associated technologies in disability research and intervention

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ABSTRACT

This paper concerns the application of virtual reality and associated technologies (VRAT) in the disability research and intervention field. By reviewing a 144 studies presented at the International Conference Series on Disability, Virtual Reality and Associated Technologies (1996-2006), our analytic work examine the underlying conceptual frameworks of disability and methodological rationales used in selected papers. In the last 15 years, there was a paradigmatic shift from the medical to the biopsychosocial model of disability. Yet, our analyses indicate that such shift is not clearly reflected in the way VRAT have been addressing disability issues. The present manuscript offers recommendations regarding definition of goals, methodological procedures, and assessment rationales in order to stimulate discussions on how the use of VRAT can be improved in the field of disability research and practice

1. INTRODUCTION

Conceptual models provide a set of definitions and principles, which introduce specific ways of looking at certain aspects of reality. Depending on how a phenomenon is described and understood, different approaches may be selected to apprehend it or to address related issues.

Disability is an occurrence that has been portrayed, over time, from several perspectives. Such views framed distinct lines of scientific inquiry into both disability comprehension and intervention. Although individuals with significant physical or mental impairments have been part of human societies even before the evolution of Homo sapiens and the existence of rehabilitation practices are documented earlier than the twentieth century (Braddock & Parish, 2001), it was not until the late 1950s that conceptual frameworks for modelling disability appeared. As a field of theory and practice, first disability constructs were clearly influenced by clinical conceptualizations of disease (Yelin, 1992).

Reference to what is now described as the medical model "(…) implies that the locus of the disability is in the person and that disability is defined by the manifestation of a health condition in the form of anomalies or impairment of physical or mental structures" (Simeonsson, 2006, p. 73). The emphasis on pathology is, consequently, the prominent feature of current approaches inspired by the medical model. According to this outlook, individuals with disability experience restrictions and limitations in their daily lives due to disease, trauma, or other health condition and require some type of intervention provided by specific professionals to "correct", "remediate", or "compensate" for the problem (Jette, 2006).

Theorists and activists from the "disability movement" (e.g., Barton, 1996; Finkelstein, 1980; Oliver, 1996) brought up sound arguments against the medical model. Adopting a sociopolitical viewpoint, they articulated the perspective that disability was not a characteristic or an attribute of the person itself, but rather a result of discrimination and exclusion created by mainstream social environments. On this analysis, the contrast between impairment and disability became a key epistemic organizer for theorizing about disability and intervention practices. As Davis (2000) contends, "(…) disability is not so much the lack of a sense or the presence of a physical or mental impairment as it is the reception and construction of that difference. (…) Impairments are physical facts, but disability is a social construct. For example, lack of mobility is an impairment, but an environment without ramps turns that impairment into a disability" (p. 56). Seeing

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disability as a social construction is indeed the basic assumption of what has been called the social model. Proponents of the social model define the degree to which an impairment is disabling in relation to societal barriers that restrict the participation of disabled people in the mainstream of social activities. Therefore, intervention efforts are focused on sociopolitical changes in order to abolish barriers, to increase access to resources, and to include disabled people into society on their own terms rather than adapt to it on other's people terms (Chen, 2007).

It seems unquestionable that "hostile" environments and disabling barriers which society (i.e., politicians, educators, architects, social workers, employers, health professionals, and others) erects dampen the quality of everyday life for many disabled people. However, the assumption that disability can be eradicated with appropriate social policies (e.g., Barnes, 1992) is undoubtedly an unrealistic expectation. It can be all too easy to believe that a person with disabilities could hold any job if only attitudes changed, the environment was accessible, or if the work was adequately organized. On the other hand, stating that disability is solely a social construction and that the body has nothing to do with it (e.g., Oliver 1996) does not acknowledge the limitations, the pain, or the discomfort, which may result from impairments that no amount of change in the social context can remove (Woodward, Witcher & Timms, 2005). The attempt to leave impairment out of account introduces a dualism that separates the body from the self. As Hughes and Paterson (1997) remark, this "(…) definitional separation of impairment and disability, which is now a semantic convention for the social model, follows the Cartesian western meta-narrative of human constitution" (p. 329).

In recent years, efforts have been made to develop new conceptual approaches with the purpose of bridging the gap between the medical and social models. Many scholars and practitioners recognize, now, the need to move towards a more holistic view of the disabled person, without making the mistake of reducing the complex notion of disability to one of its aspects (Williams, 2001). The focus on the *whole-person* is congruent with emergent biopsychosocial perspectives on disability.

A key principle of the biopsychosocial framework is that biological, personal, and environmental factors are interactively involved in human functioning. (Suls and Rothman, 2004). As recently operationalized within the As recently operationalized within the International Classification of Functioning, Disability and Health – ICF (WHO, 2001; 2007) – biological factors encompass all aspects of *body structures* (anatomical parts of the organism such as organs, limbs, and their constituents) and *body functions* (physiological and mental functions). Any significant loss or deviation at the level of bodily structures or functions is termed impairment. Although impairments may have origin in pathological processes, they "(…) do not necessarily indicate that a disease is present or that the individual should be regarded as sick. Impairments are broader and more inclusive in scope than disorders or diseases; for example, the loss of a leg is an impairment of body structure, but not a disorder or a disease" (WHO, 2007, p. 13).

The biopsychosocial approach recognizes the difference between people's capacity and performance – which in the ICF model are respectively used to qualify *activities* (execution of tasks or actions) and *participation* (involvement in real life situations). The capacity describes an individual's ability to act at his or her own highest level of functioning while performance portrays what the individual is actually able to do in his or her current environment. One can easily see how impairments may limit personal activities or restrict participation in communal life. However, the facilitating or restricting roles of the environment should also be accounted. Let us imagine the case of an individual with severe spinal injury. Suppose that this condition has generated impairments at the level of the lower limbs, disabling the functional use of the legs (paralysis). If by chance the individual has no available resources to reduce personal limitations in the execution of activities that require displacements and "navigation" through space, he or she would be particularly susceptible to experience disability. Yet, the provision of mobility aids and the arrangement of adequate environmental accommodations could be a viable way to decrease the gap between current capacities and the desired performance in daily life situations. The individual would thereby feel more independent and less likely to meet restrictions in his or her ability to participate in educational, employment, recreational and societal activities.

While acknowledging that disablement may involve dysfunctions at the biological level, the biopsychosocial framework adopts a *whole-person* approach, placing a special emphasis on the dynamic interaction between the individual and its environment. This notion of person-environment interaction is echoed in a change of focus from strict documentation and treatment of impairments, to a wider view that addresses independent functioning in daily living situations (Simeonsson, Pereira & Scarborough, 2003). Traditional (re)habilitation practices often involved a belief that individuals with disabilities should be trained to perform activities and tasks "normally". Most impairment-based interventions have taken "normality" as the guiding reference to decide about what is recommended and prescribed for each case (Ravaud & Stiker, 2001). Such understanding discards the perspective that autonomous functioning within the physical and social world – including the possibility of actively engaging in recreational and leisure activities – might be the most valued goal for those who experience participation restrictions. In the context of human disability, a more comprehensive approach may imply encouraging the liberal use of "augmentative" supports such as mobility aids, alternative communication devices and related technological tools, which can play a significant role in the lives of people whose functional abilities are likely to be improved with such resources. For example, in some situations, it may be less relevant to train specific formal skills like "talking" or "walking" than to provide means for "being able to communicate effectively" or for "becoming autonomously mobile". In this sense, the biopsychosocial model asks to accept variation and to appreciate what disabled people can do to achieve personal and social valued outcomes in whatever ways are possible with their particular range of interests, skills, and limitations (Rosenbaum, et al., 1998).

During the past few years, there has been a fast expansion of technological resources designed to assist disabled individuals. In this context, the International Conference (series) on Disability, Virtual Reality and Associated Technologies (ICDVRAT), became an important forum where service providers, academics, and other experts examine how such technologies can be used in the area of disability research and practice. Held biennially since 1996, the ICDVRAT has built a community, which "(…) includes practitioners, educators, researchers, technologists and end users from schools, hospitals, disability service providers, rehabilitation institutes academic research, scientific institutes and technology development labs drawn from a variety of disciplines including medicine, healthcare, education, computer science, psychology and engineering" (Cobb & Sharkey, 2007, p. 51). The term "Associated Technologies" was added to the expression "Virtual Reality" to encompass a great variety of approaches and technologies.

Assuming that the proceedings archive of the ICDVRAT (available from the web site *www.icdvrat.reading.ac.uk*) provides a representative sample of the studies conducted in the field, our paper analyses a significant number of studies presented at the last conferences. Aiming to stimulate discussions on theoretical issues that may be useful to improve the application of VRAT in disability research and intervention, our review explores four major topics:

- The identification of the conceptual frameworks of disability that have been underlying the employment of VRAT in the examined studies.
- To what extent key components of functioning and disability (e.g., body functions and structures, activities, and participation) have been addressed in assessment or intervention processes mediated by VRAT.
- To what extent technological applications designed to deal with activity limitations have been including contextual factors focused on promoting participation.
- To what extent intervention research designs have been concerned with evaluating effects of VRAT applications through performance assessments in the real world

2. METHOD

2.1 Sample

A total of 144 papers were selected from the online proceedings archive of the International Conference Series on Disability, Virtual Reality and Associated Technologies. To be sampled, papers should explicitly document the use or explain the potential value of the described VRAT system in the assessment or the rehabilitation of persons with disabilities.

2.2 Procedure

Textual analysis (often called content analysis) is a standard methodology used to determine and quantify the presence of certain concepts within documents. To conduct such an analysis, contents of texts are examined and coded into categories according to their conceptual properties. Contents of the selected papers were analyzed through a coding scheme with a set of detailed instructions developed by the authors. Each paper was independently coded by three of the authors. Codes were compared and agreements were generally above the 90 % level in each coding category. Disagreements were discussed until divergences ceased.

2.3 Coding Scheme

The development of our coding scheme was based on a deductive approach, considering basic conceptual components of the examined papers. In the created system, coding categories were defined in five major sets: the *general classification* set, the *identifier* set, the *addressed components of human functioning* set, the *contextual factors* set, and the *performance assessment* set.

2.3.1 General Classification Categories. Disability paradigms or models are made up of several concepts, which reference the theoretical, definitional, and taxonomic views toward disability. Although prone to criticisms, we decided to use three classifiers to categorize the papers. The classifiers were developed taking into account the fundamental premises of the medical, the social and the biopsychosocial model (see table1).

Table 1. *Classifier categories used to assign studies to the medical, social, and biopsychosocial model.*

Medical	Disability is an individual phenomenon, resulting from underlying pathology, which is reflected by impaired functions. The target of intervention is primarily individual with no emphasis on families, schools, and employers. Purposes of interventions are rehabilitative, focused on body functions. Used or described technological applications are designed to address the improvement, the recovery, or the assessment of impaired functions.
Social	Disability is seen as a social construction and is defined as limit or loss of opportunities to take part in community life because of physical and social barriers. Targets of intervention are the communities, social attitudes, and political systems with the purpose of producing change in social, economic, and political structures.
Biopsychosocial	Synthesizes what is relevant in the medical and social models, without reducing the complex notion of disability to one of its aspects. Disability is seen as a consequence of complex interactions between health, personal and environmental factors. Disability is described in terms of difficulties in the execution of specific activities and tasks or constraints that individuals may experience in engaging in real life situations. Elements addressed in assessment/intervention are activities performance, participation, or environmental factors. Used or described technological applications are designed to promote individual's involvement in daily activities.

Because information provided in a number of papers was limited, coders had to use some inferential procedures to classify the studies. Surprisingly, such cases did not produce coding disagreements. As in the other sets of categories, detailed instructions regarding coding decisions are available from the authors.

2.3.2 Identifier Categories. The identifier set (see table 2) includes codes for processing information on how participants or potential users of technological applications have been characterized in each of the examined papers.

Table 2. *Identifier codes used to characterize participants or potential users of technological applications.*

Pathology	Specific use of a nosographic category (disease, disorder, injury…) to typify study participants or define potential users of a technological application
Impairment	Allusion to mental or physical impaired functions in order to typify study participants or define potential users of a technological application
Activity limitations	Mention to difficulties in the execution of specific activities and tasks as a way to typify study participants or potential users of a technological application
Participation restrictions	Indication of the constraints that individuals may experience in engaging in real life situations to typify study participants or potential users of a technological application

In one case (Maxhall et al., 2004) no category could be assigned because participants were non-disabled health professionals.

2.3.3 Addressed Components of Human Functioning Categories. This is a major set of categories that concerns the components addressed in assessments/interventions with VRAT systems (see table 3). To identify the representative components of functioning and disability, we used the linking rules proposed by Cieza (2005) to connect paper contents to the dimensions of body functions, activities and participation. These rules allow us to link and systematically compare meaningful concepts of the examined studies to the above-mentioned components. However, as Badley (2008) contends, there is not a clear distinction between activity and participation. To surmount this difficulty, the author suggests the use of the terms *acts*, *tasks*, and *societal involvement*. Acts are basic activities. Examples of acts include walking, standing, thinking, talking, and griping. Acts serve as a link between body functions and structures and tasks as they concern the impact of impairments on functioning. Tasks relate to purposeful things that people do in daily life in specific contexts. Tasks include most of what is comprehended by the terms "activities of daily living" or "instrumental activities in daily living". Tasks usually comprise coordinated, sequenced, and often synchronized acts. So for example, the task of dressing may require a range of acts such as reaching, holding, grasping and so on. Societal involvement concerns the individual as a player in socially or culturally recognized areas of human endeavour. Examples of societal involvement include involvement in work and employment, in leisure activities, in parenting, and in community or civic life.

Table 3. *Components of human functioning.*

Body functions and structures	As defined in WHO (2001; 2007), Body Functions are physiological functions of body systems (including psychological functions), and Body Structures are anatomical parts of the body such as organs, limbs and their components.
Activity (acts or tasks)	Acts are basic activities like walking, standing, , talking and griping. Tasks relate to the purposeful things that people do in daily life in a specific context, and usually comprise coordinated, sequenced and often synchronized acts.
Participation (societal involvement)	Concerns the individual as a player in socially or culturally recognized areas of human endeavour. Examples include roles such as work and employment, leisure, parenting, and community, social and civic life.

These three components – acts, tasks, and societal involvement – make possible to differentiate between activities and participation in two distinct ways. Bradley (2008) suggests the possibility of taking acts on one side, keeping tasks together with societal involvement to represent participation. On the other hand, the split could be made between tasks and societal involvement, equating participation with societal involvement. On this study, we followed the second option, assuming that participation is equivalent to engagement in social roles and that activity is related to the performance of acts and tasks.

2.3.4 Categories for Contextual Factors. Inclusion of contextual factors focused on promoting participation was examined through the categories described in table 4.

Table 4. *Contextual factors.*

Settings similar to everyone in society	Real world settings or of loyal reproductions of real physical/social contexts similar to everyone in society (such as supermarkets, streets, restaurants)
Individualized contexts	Real world settings or of loyal reproductions of real physical/social contexts that are or duplicate a specific living context of the individual.

2.3.5 Assessing Performance in the Real World. This analysis examines whether intervention research designs have been concerned with evaluating effects of VRAT applications through performance assessments in the real world.

2.4 Data Analysis

For reasons of brevity, studies are not referenced in the performed analyses. All examined papers can be found on line at the proceedings archive of the conference series.

3. RESULTS

3.1 Selected Papers and the Total Number of Documents

As formerly indicated, we adopted a large criterion to select papers. In order to be sampled, a study should document the use or just describe and explain the potential use of a VRAT application in the assessment or rehabilitation of persons with disabilities.

Table 5 shows that there was a general increase in the proportion of the selected documents from 1996 to 2006. This finding reflects the fact that papers focused on broad considerations about applying technologies in the field of disability gave progressively place to problem-driven approaches in which intervention targets and end-users were more precisely specified.

Table 5. *Percentages of sampled documents in each of the examined years.*

	TOTAL NUMBER	SAMPLED NUMBER	PERCENTAGE
1996	30	16	53.33 %
1998	31	16	51.61 %
2000	42	31	73.81 %
2002	34	24	70.59 %
2004	43	27	62.79 %
2006	40	30	75.00%
TOTAL	220	144	65.54 %

3.2 Conceptual Frameworks of Disability Underlying the Use of VRAT Applications

The social model defines disability as a limit or loss of opportunities to take part in community life because of physical and social barriers. Intervention practices focus on the societal conditions that create disadvantage for people whose individual characteristics are outside the social norm. Thus, for the social model, intervention goals address changes in the fundamental economic, communal, and political structures of society. Given the contents and scopes of the examined papers, no one could be unmistakably assigned to the social model.

Considering the basic conceptual components of the medical and biopsychosocial approaches, our analyses showed a predominance of biopsychosocial-oriented studies in the 144 scrutinized publications. However, proportions presented in Figure 1 reveal an atypical progression trend in the adoption of both models across the years.

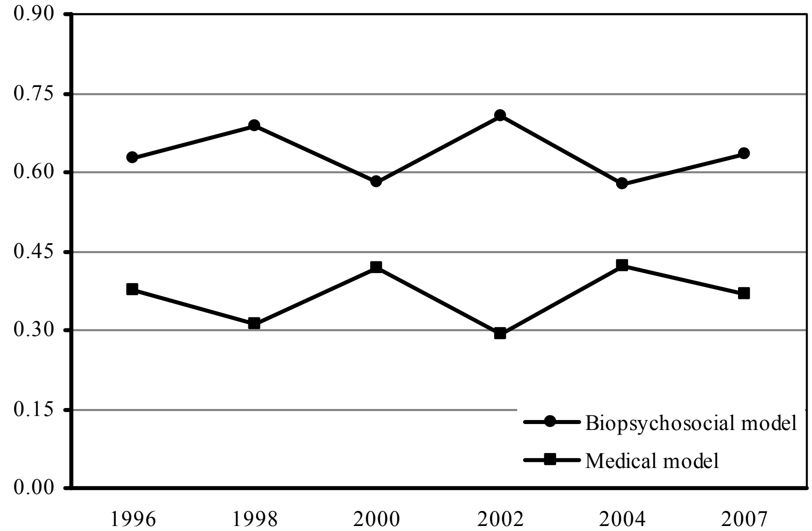

Figure 1. *Proportion of studies representing the medical or the biopsychosocial view in each of the sampled years.*

Actually, the relative amount of papers embracing the key notions of the aforementioned orientations remained more or less stable over time, suggesting that different coexisting perspectives have been sustaining the employment of VRAT in the field of disability research and practice.

3.2 Addressed Components of Human Functioning

Activities were the most addressed component of functioning in the examined studies (see Fig. 2). Consistent with the significant number of approaches based on the medical model, body functions were an important focal point of assessments and interventions mediated by VRAT applications in a substantial percentage of papers (34.03 %).

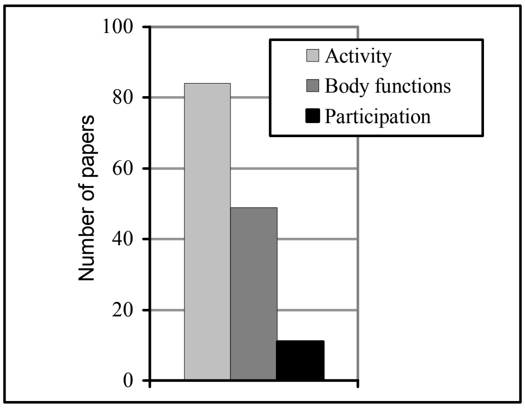

Figure 2. *Number of studies addressing Activity, Body Functions, and Participation with VRAT applications.*

Mentions to the participation component appeared in only 7.64% of the sampled studies. Moreover, coherent to the fact that we could not find any approach conceived within the theoretical realms of the social model, no paper described participation restrictions (i.e., constraints that individuals may experience in engaging in real life situations) to characterize participants or potential users of technological applications. Regarding such characterization, allusions to pathology (i.e., nosographic category) and to mental or physical impaired functions appeared respectively in 31.25% and in 56.94% of the papers; references to difficulties in the execution of specific activities and tasks (activity limitations) appeared in only 11.81% of the examined cases. Overall findings reported in this section remained quite stable across the years, with little and atypical variations.

3.3 Inclusion of Contextual Factors

As previously described (see Table 4), contextual aspects refer to real settings or to loyal reproductions of existent physical/social contexts. These reproductions – mostly provided in VE platforms – include settings similar to everyone in society (e.g., supermarkets, streets…) or individualized contexts (e.g., home, school…) that duplicate characteristics of a specific environment.

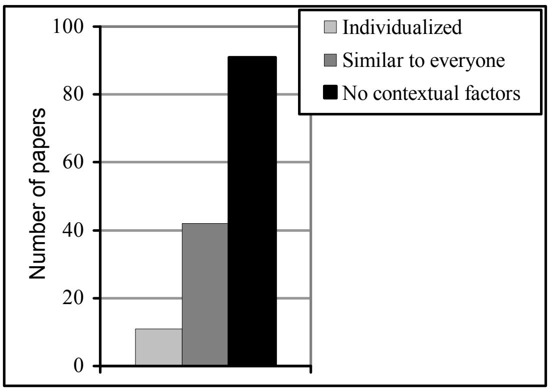

Figure 3. *Number of studies of studies including contextual factors in VRAT applications.*

Figure 3 show that a large majority of the studies did not incorporate contextual factors (63.19 %). Individualized contexts (7.64 %) were less included than "replicas" of settings similar to everyone (29.17 %).

3.4 Performance Assessments in the Real World

Ecological concerns should be central in interventions addressing disabilities. The ultimate goal of any therapy or training is to improve functioning so that the client will be able to achieve participation in their real world environments by overcoming, adapting to, or minimizing the environmental barriers (Kizony et al. 2004). Thus, one crucial point was to examine to what extent studies had been concerned with evaluating effects of VRAT applications through assessments in the real world. Only a residual number of papers

(4.86%) reported such evaluation, indicating that issues regarding evaluation of daily activities and participation in the real world were seldom addressed.

4. DISCUSSION

The present paper used textual analysis to examine some of the basic conceptual grounds that have been underlying the employment of VRAT applications in the field of disability research and practice. Our analyses focused on a significant number of documents available from the proceedings archive of the International Conference (series) on Disability, Virtual Reality and Associated Technologies. These documents were selected, assuming that they stand as a representative sample of the studies produced in the domain. In the discussion that follows, we reference only a small number of the analyzed papers. Their choice was in most cases arbitrary, serving illustrative purposes. Others could be chosen, but it was not possible reference them all.

A variety of theoretical perspectives has been proposed to understand, explain, and address disability problems. According to our review, the majority of the examined papers seem to embrace key fundamental assumptions of the so-called biopsychosocial model. Yet, crucial premises of the medical model also appear as chief conceptual organizers in a very significant number of approaches. It is noteworthy that the incidence of studies representing both orientations remains relatively stable along the sampled years. Apparently, such finding suggests that VRAT applications are being implemented within the realms of different outlooks. However, different perspectives do not necessarily reflect the coexistence of irreconcilable worldviews. The biopsychosocial model contends that disability is an occurrence that involves complex interactions between biological, personal, and environmental factors. Although such factors are inextricably connected, one has to acknowledge that some aspects of disability are preponderantly internal to the individual. Consequently, in some cases, impairment-based interventions can be valuable strategies to address disablement processes (Bowen et al., 2003). As a guiding framework, the biopsychosocial approach challenges practitioners to evaluate comprehensively all aspects of a problem and to take knowledgeable decisions concerning the most relevant levels at which address interventions.

The biopsychosocial framework highlights the meaning of person-environment interactions, placing special emphasis on aspects that may enhance individuals' capacity to execute actions and tasks. Mentions to VRAT applications for reducing activity limitations are predominant in the examined studies. Most of these studies describe devices designed to facilitate the interaction and navigation on computers and internet systems (e.g., Caffrey and McCrindle, 2004, Battersby et al., 2004), communication aids for persons with aphasia (e.g., Ahlsén and Geroimenko, 1998), or technologies to provide assistance in wheelchair control (Mori et al., 2002). Others use VE for training everyday activities, such as preparing coffee (Hilton et al., 2000), street crossing (e.g. Katz et al., 2004; Lam et al., 2004), or shopping (e.g. Cromby et al., 1996).

Results indicate a poor incidence of studies dealing with participation issues. Yet, a few number of approaches present technological solutions aimed to reduce exclusion. Among other examples, we mention the case of the *meeting support system* designed to help persons with hearing impairments to attend reunions without the need of note-takers or sign interpreters (Shikata et al., 2006). Though still in an early stage of technology development, the system holds the promise of enabling users to distinguish the mainstream content of meeting discussions from the irrelevant chattering which usually takes place in those kinds of context. Interventions focused on participation require the use of strategies to habilitate environments. An example of *environmental habilitation* is documented in a report that describes how computer technology and human machine interfaces were used to provide multissensorial experiences for attendants of classical orchestra music concerts (Brooks, 2004). Specifically addressed to individuals with hearing impairments – who exclude themselves from these events – the intervention did in fact enhance the experience for not only the impaired members of the audience, but also for the other attendants. This observation is in line with the argument that fostering participation through *environmental habilitation* strategies should bring benefits for those to whom the intervention is intended and for those to whom the accommodations are not necessarily required. Inclusion – seen as an end-result of non-restricted participation – means that people with disabilities "are allowed" to take part in the mainstream of social activities (Chen, 2007). Therefore, one feature of inclusive environments is that they should be designed in order to enrich experiences for everyone.

The same principle applies to assistive-type technologies. Many people with disabilities use assistive technologies to enhance their level of independence and to increase their participation in educational, employment, recreational, and community activities. Unfortunately, these devices lag behind mainstream products in terms of innovation, availability, quality, and cost. The trading system for assistive technologies is characterized by small markets, special manufactured products and small companies, with limited resources. To overcome these challenges, the design of assistive devices should seek universal rather than particular usability. Even though we can find occasional considerations about methodological strategies regarding development of guidelines for *universal design* (e.g., Pareto and Snis, 2006), this issue has not been systematically addressed and discussed in the sampled studies.

Contextual aspects appear predominantly in approaches that use full-immersive VE. Many of these systems are based on everyday activities such as taking the bus, going shopping, or visiting a café. As argued elsewhere (Rose et al., 2005), the advantage of using VR environments lies on their potential to simulate many real-life and imaginary situations, providing the opportunity for more ecologic assessments and training. They have also the flexibility to enable sensory presentations, manipulate the task complexity, and adapt response requirements to the users' capacity. Furthermore, they provide activity settings in which users can practice skills safely, without experience potentially dangerous real world hazards. Interaction with environmental factors is a fundamental aspect of the scientific understanding of disability. Environmental factors range from physical dimensions (e.g., geography, spatial human-made arrangements) to social attitudes, community organizations, economic systems, and laws. Using VE in disability research and practice makes more sense when interactions between physical factors and personal variables are considered. Since most applications provided *settings similar to everyone in society*, consideration of the idiosyncratic qualities of such environments was probably impoverished. Thus, one of the challenges in designing VE scenarios is to use parameters adjustable to each user (see Andersson et al., 2006).

Virtual reality training has been used as a therapeutic tool for individuals with disabilities. On the other hand, social attitudes are components of the environment and negative attitudes may create restricting participation barriers. Maxhall et al. (2004) used VE to improve empathy in professionals who care for patients with strokes. The scenario looked like a normal apartment that could be experienced with some of the perceptual distortions caused by strokes. The simulated environment was effective in influencing positively subjects' empathy. This study is unique in the examined sample, because no other has ever addressed attitudes in surrounding social environments of people with disabilities.

A very small number of studies have been concerned with evaluating effects of VRAT applications through performance assessments in the real world. Examples are demonstrations of successful transfer of training from virtual environments to the real world (e.g., Cobb et al., 1998; Cromby et al., 1996; Katz et al., 2004). In part, this is due to the fact that many reported research "has not yet reached the stage at which evidence in practice can be demonstrated" (Cobb and Sharkey, 2007, p. 63). Such findings also suggest that one key principle of rehabilitation – i.e., treatments should maximize functioning and independent living in the real world – has yet to be incorporated in the mainstream of research designs.

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ICDVRAT 2008

Session IX

Helping Through Music

(Casa da Música)

Co-chairs: Rolf Gehlhaar & Ben Challis

Infrared sound and music controller for users with specific needs

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ABSTRACT

The design and rationale behind a novel music and sound controller ("The Benemin") is described. Using an array of eight low-cost infrared distance measuring sensors, the system enables users to trigger and manipulate sounds using MIDI messages. Although the controller can facilitate complex musical interaction, providing eight note polyphony and expressive control, the central theme of the project has been one of accessibility. The controller is designed to be used in a variety of settings by users with special needs and has been designed to be both intuitive to play and easy to set up. An ongoing programme of user testing is described and discussed alongside preliminary results.

1. INTRODUCTION

There are two key hardware systems in regular use within the UK that are aimed at bridging the gap between an individual's desire to interact with sound and the physical and cognitive barriers that can obstruct that same desire. The first, and probably the most commonly available technology, is Soundbeam. This uses an ultrasonic sensor to create an invisible 'beam' that is mapped to musical pitches along its length. The other system, MIDI Creator, allows various types of sensor to be utilised for the same purpose; this includes an ultrasound sensor similar to that used by Soundbeam. Both systems provide immediate interest by allowing the user to produce and interact with sounds that are triggered by MIDI messages. With this in mind, both systems can be regarded as inspirational and accessible music systems where the kinds of interaction encouraged are achievable by individuals with limited mobility. Additionally, when working with individuals with severe learning difficulties, such devices can be a particularly intuitive method for exploring and encouraging cause-and-effect style interaction. At a higher level, both systems can also be thought of as musical instruments where the notes produced are being manipulated to create melodic fragments and rhythms. Again, the type of interaction afforded is flexible to the needs of users with limited mobility. However, when systems such as these are considered as musical instruments in this way it becomes important to consider their relative merits within a context of structured music-making activities. It is not the intention of this paper to unduly criticise either of these two systems, indeed it is acknowledged that both offer strong music making potential. However, comments and observations gathered from practitioners working within special needs education suggest that there would be a place for a more dedicated musical instrument of this nature that offers similar levels of accessibility but with less complexity in terms of setup and operation.

1.1 Musical Tasks

At the most basic of levels, the building blocks of western music can be regarded as pitch, harmony and rhythm. However, the combination of pitch and rhythm provides us with *melody* and the layering of pitches provides us with *harmony* and it is typically the combination of these two along with *rhythm* that are used when making specific reference to musical ideas. However, the types of musical instruments that we use and the way in which we perform with them also provides us with expressive qualities such as timbre and loudness. Indeed, the level of *expression* afforded by one instrument in comparison to another can be just as significant as the different types of musical task that either can achieve. In terms of accessibility and music, it would be desirable for any enabling-instrument to be as flexible as possible in terms of the different types of musical task that can be achieved whilst also offering considerable expressive control.

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One quite fundamental musical task would be to copy or improvise a *rhythmic* pattern. For this task, the sound used does not need to be pitched but the player will need to be able to move freely from one sound to another at specific times. With Soundbeam, this can be limiting as to move from one sound to another the user must either move within the beam (triggering any sounds between the ones being targeted) or remove the hand or other body part being used and re-enter the beam at an alternate location; this can be difficult to gauge. MIDI creator has the same limitations when using the ultrasound sensor but is less dedicated in its design such that there is clear potential to use a number of sensors of different types for different purposes. However, this requires the user to decide which sensors will be used and how they will function; this creates additional levels of complexity in terms of ease-of-use. It also requires that a variety of different sensors be readily available.

If a rhythmic task is performed but the sounds used have pitch, then the task becomes *melodic*. Melody will typically be associated with tonality and a musical key. Both Soundbeam and MIDI Creator allow predefined or programmable scales to be mapped across the sensor(s). Although, the earlier limitation remains true Soundbeam, in particular, is effective at creating musical textures where it may not be of significance whether the musical ideas are, in part, produced as a result of a rule-based performance behaviour. There are numerous inbuilt functions within the system for creating melodic, rhythmic and harmonic ideas but access to these depends on how adept an individual is at understanding and programming the system.

Finally, if more than one pitch is played at the same time the task can be thought of as *harmonic*. An instrument's ability to produce harmonic sounds is limited by its polyphony. For example, a flute is monophonic, producing only one note at a time whereas a standard guitar is six note polyphonic allowing chords to be sounded. In this respect, Soundbeam is essentially monophonic although it is possible to sound chords that have been programmed into the system. MIDI Creator has the potential to be polyphonic but again requires additional levels of customisation to make this possible.

A basic requirement for an instrument to be *expressive* would be that individual notes can be sounded at different levels of loudness. On some acoustic instruments, the loudness of a sustained note can be changed over time which is a particularly expressive quality. Additionally, it is often possible to alter the timbre of a note by adjusting the way in which it is played, again, this is a very expressive quality and one that can also be regarded as desirable.

2. PROJECT AIMS

2.1 Overview

The central aim of the "Benemin" project has been the design and realisation of a controller-style musical instrument that can afford complex levels of expression and interaction whilst also fulfilling the inspirational role that can be instrumental in attracting and maintaining a user's interest. At its most basic level it should operate as an 'inspirational' musical toy, an object that encourages users to interact because of the connection between the actions they are making and the sounds being produced (cause-and-effect). As identified earlier, this would have direct application within an educational setting for users with severe learning needs. At a higher level, it should be capable of more structured musical interactions such that users can shape and develop simple but coherent musical ideas (melodies, rhythms and simple harmonies). At a higher level still, it should operate as a performance tool that can facilitate more complex levels of musical and expressive control. In addition, the controller should be as accessible as possible, being flexible and adaptable enough to respond to different levels of mobility and dexterity on the part of the user. It should also be intuitive to use and simple to operate. Finally, it was also recognised that the overall cost of the instrument should be regarded as significant within the design process.

There would be advantages to be gained from such a system. Practitioners working in educational and/or community-based settings would have the potential to use a single instrument with users across a broad range of physical and cognitive abilities. This is also advantageous to education providers where specialist technology can often be very expensive; the more flexible the system is, the more likely that it can be used in a variety of settings. If the system is intuitive to use and simple to set up, it is likely that more staff will be able to easily use the equipment with an increased potential for autonomy on the part of the learner within educational activities. Key issues explored within the design process have been musicality, usability, accessibility and affordability.

2.2 Musicality

As was discussed earlier, the more polyphonic an instrument is the more capable it will be in terms of producing rich and potentially complex harmonies. However, even being able to sound two notes simultaneously provides the basis for introducing a simple major or minor interval; this alone, can be enough to reinforce the tonality of a musical idea. With this in mind, it was identified that the instrument should be two-note polyphonic at minimum but with a view to increasing this figure if possible.

At minimum, it would be desirable to have control over the loudness of the notes being played with the instrument. However, many musical instruments allow dynamic control within the life of a single note (wind instruments in particular). For example, a saxophonist can sound a note and then control the loudness with increased or decreased airflow; this can also change the timbre of the sound being produced. This is a particularly expressive musical effect and yet one that is simple and intuitive to understand. It was decided that at minimum, the instrument should be able to achieve different levels of volume but that the possibility for dynamic change in the quality of the sound should also be explored.

2.3 Usability and Accessibility

The two devices described earlier (Soundbeam and MIDI Creator) both carry significant learning-curves in terms of acquiring an adequate understanding of how to operate, adapt and expand the system. This is an observation that has been offered by educators prior to the design process and has also been echoed further during the testing process. The feeling appears to be that these systems are not used as frequently as they might be as there may only be one member of staff within a school or institute who is fully knowledgeable in its use. However, the gesture-based approach to triggering sounds offered by these devices appears to be both intuitive and flexible in terms of facilitating access for users with limited mobility. Traditional musical instruments tend to require high levels of dexterity in terms of control and movement of individual fingers; they often require the use of both hands in this way. With this in mind, it was decided that a gesture-based approach to interaction where one or more hands (wrists, arms etc) could be used to play individual notes would be highly desirable but that the general complexity of the system should be kept as simple as possible.

2.4 Affordability

Specialist technology within the educational setting is often expensive and this factor alone can impact on whether individuals are exposed to a particular experience or not. It was decided that one of the aims of the project should be to try and keep the overall cost of the instrument as low as possible. One key aspect that was identified as being significant within this was the choice of technology to be used for sensing movement. Ultrasonic sensors can have considerable range and accuracy, however, they are also particularly costly unless considered within the context of mass-production. In contrast to using this type of technology, it was decided that the project should explore possibilities for the use of low-cost infrared sensors.

3. DESIGN

3.1 Performance Behaviour

According to Malloch et al. (2006), Digital Music Instruments (DMIs) can be categorised within three distinct modes of performance behaviours: skill-based, rule-based and model-based. Of these, the mode of musical interaction-behaviour most similar to that of playing a conventional musical instrument lies within the skill-based domain. The implication is that the user will be interacting in real-time in response to a continuous audio-stream. The other two models of musical interaction-behaviour operate at increasingly abstract levels of interaction with the user's interactions being less and less involved in terms of immediacy of output. Based on these definitions for performance behaviour, the central design consideration was for the system to employ a completely skill-based approach to interaction; a user's movements should be directly interacting with and affecting the sound that is output. Although it may be desirable to be able to create unusual and perhaps quite complex musical textures through the use of rule-based behaviours, this can be achieved separately with third-party software. With this in mind, it was decided at an early stage that the Benemin should be thought of simply as a diatonic instrument that is both accessible and expressive.

3.2 Hardware

The current working prototype is based on the Sharp GP2Dxx series of infrared (IR) distance measuring sensors (see Fig 1.). These are particularly versatile sensors that are commonly used in robotics for detecting objects within a limited field or 'beam'. Discussion on the relative merits of IR sensors is provided by

O'Sullivan and Igoe (2004) and also by Miranda and Wanderley (2006). Essentially, each sensor unit includes an IR transmitter-receiver pair that provides continuous feedback on whether an object is within the 'beam' of the sensor. Although these have a shorter range than ultrasonic sensors they are less costly and also more self-contained. GP2Dxx sensors are available as digital output devices (providing logic-high or logic-low according to a distance threshold) or as analogue output devices (providing a voltage that represents the distance from the object to the sensor). These units are low-cost and require minimal additional electronics making it relatively easy to incorporate a number of them into an array. The unit in use within the current system provides analogue output for distances in the range 10cm to 80cm.

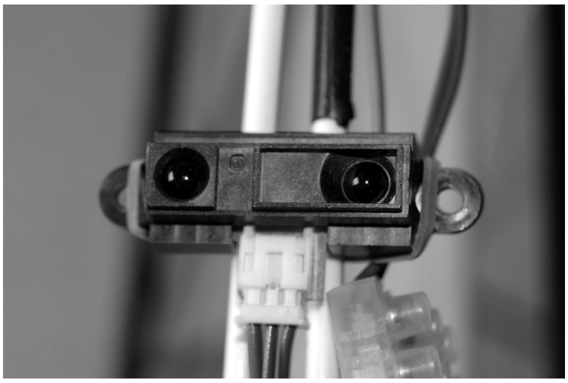

Figure 1. *Sharp GP2Dxx series IR distance measuring sensor.*

For the initial system, eight sensors have been attached in line to a light-weight curved-frame with the sensor 'beams' orientated upwards in front of the performer's body (see Fig. 2). This curved layout is for practical reasons rather than aesthetic as IR sensors of this type can have a tendency to trigger neighbouring units that are in close proximity if their beams overlap. The curvature of the frame aids in pointing the sensors away from each other slightly such that the distance between any two can be kept to a useable size (approximate to a hand's width). The overall height of the frame above its base is 22 cm and the overall span between the extreme sensors is 92cm with a distance of approximately 14cm between neighbouring sensors.

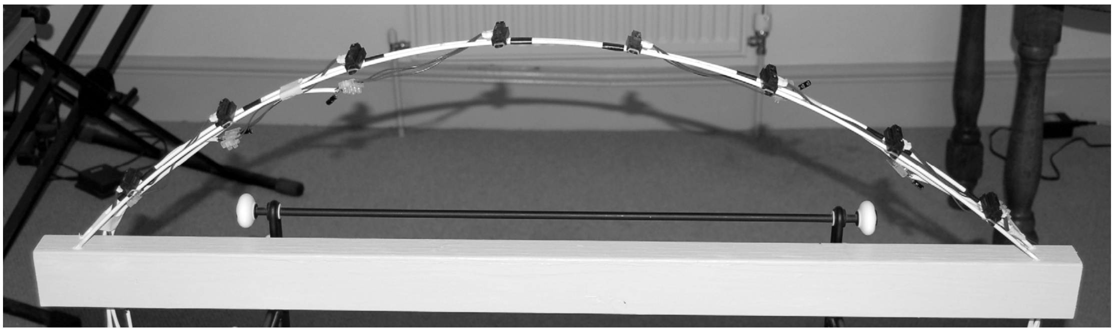

Figure 2. *The Benemin.*

A programmable microchip is used to run software that maps the change in voltage onto standard MIDI note and/or controller messages which are then relayed to any hardware or software sound-generating device that is connected. The system can be regarded as being eight note polyphonic as all sensors are read and acted upon independently of each other. However the actual polyphony achieved will, in part, depend on the capabilities of the hardware or software being controlled.

3.3 Functionality

The Benemin can be used in two different ways depending on the nature of the hardware it is controlling. In its first mode (*instrument*), the system simply transmits Note On and Off messages accordingly as an object enters or leaves a beam, these have a velocity (loudness) that corresponds to the distance from the sensor to the object (finger, hand, arm etc.). This is useful for working with standard MIDI sound modules or synthesisers with the controller functioning in a similar fashion to a MIDI keyboard. The pitches produced are currently taken from pre-defined scales and modes that are mapped from left to right (lowest pitch to highest pitch). In this mode, the controller can be thought of as a diatonic instrument where each note is a specific step within one of a number of available scales (major, natural minor, harmonic minor, pentatonic, blues, dorian, mixolydian etc.). Although, these scales are currently predefined, it would not be difficult to introduce some level of user programming to this aspect. In the current version, *instrument* is the default mode along with a scale mapping of C major starting at middle C.

In its second mode (*controller*), the Note On and Off messages are still transmitted but there is an additional stream of controller messages available whilst the object remains within the beam. These change accordingly as the object is moved closer or further away from the sensor. The MIDI specification does not allow for individual note volumes to be changed dynamically but it is possible to incorporate this effect using sound programming environments such as MAX MSP and Reaktor (the full MIDI specifcation is available as a standalone resources but is covered in considerable depth in various general texts e.g. Huber (1998).) This mode provides the basis for achieving some level of expressive control. A Note On message can be used to trigger a sampled pitch or sound, the subsequent controller messages can then be used to alter the sound dynamically. This could be used to alter loudness of an individual note but could equally be used to alter its tone.

4. TESTING

4.1 Overview

As described earlier, the central aims of the project have been to design an accessible music controller, one that is easy to play and set up but also one that can accommodate a fairly broad range of user abilities and musical applications. This means that there are a number of different target groups that need to be considered within a context of user-testing. For the purposes of the testing programme for the Benemin, three contrasting user-groups have been identified. The first group includes users who have severe learning needs and in this context the Benemin is being seen as an inspirational device where simple cause-and-effect interaction can encourage a user to exercise and develop cognitive and motor skills. The second group includes users who have mild learning difficulties but probably also have some level of restricted mobility. The final group includes users where limited mobility is the most significant constraint.

A Specialist Teacher for pupils with multiple sensory impairment is working with a variety of users with differing individual needs using the Benemin system in its default operating mode (*instrument* as described earlier). Feedback is being gathered through close observation of individuals using the controller along with the critical evaluation of additional specialists working in the same environment. Group sizes are typically in the order of four or five individuals within a group but with generally only one person interacting with the device at any given time. For the purposes of the initial phase of testing there is no specific script being followed i.e. the testing is not task-specific. Where possible and appropriate, users are simply allowed to interact with and learn how to use the device in a way that works for them. It is important to appreciate that the system is currently being assessed within a working educational programme and, as such, intervention from the observer is acknowledged as appropriate. With this in mind, where an individual has perhaps struggled to comprehend or interact easily with the system it would be both acceptable and appropriate for the individual to be encouraged to attempt a different action. The difficulties that were apparent are then recorded. It is envisioned that the majority of the data gathered will be qualitative in nature.

4.2 Preliminary Results

At present, the testing programme is focusing on the first two user groups. A selection of individuals from the third user group have been identified to take part in testing. They have been working for some time with a specialist music therapist experiencing various musical activities using conventional instruments and technology. It is anticipated that this will be a particularly rich source of feedback but testing with this group will not be possible until later this year.

One group of young adults from the first user group has been observed working with the Benemin but observation within the group has quickly demonstrated that the current shape of the device is not as effective as was originally anticipated. This is not completely surprising as the curved shape, height, width and layout of sensors on the first prototype are based on relatively arbitrary measurements. There are a number of issues that are worth discussing here, the first being that the overall height of the sensor array can be quite awkward to reach for a user with severely limited movement. This is because the array has been mounted on a curved frame to point neighbouring sensors away from each other to reduce spurious triggering. The slope of the curvature can be reduced significantly to help make this less of an issue. In a similar way, the width of the array is also an issue in terms of reaching the extremities. The width, in part, is governed by the number of sensors in use. Eight sensors are available but really only to provide enough notes to produce usable musical scales. When used in a cause-and-effect style activity this number could be greatly reduced.

Some of the individuals from this group were in wheelchairs and it has been suggested that the curved shape of the frame might be an asset for this type of use if the base could be removed. Ultimately, it was also quite apparent that the body of the prototype is simply not robust enough to be used effectively with this particular user group yet and that this clearly needs to be addressed before testing can be continued adequately and safely. Although it is disappointing that the results with this group have not been as immediately promising as had been hoped they are greatly informative and are contributing significantly to the redesign of the overall layout and shape of the device.

In contrast, testing with two further groups made of individuals from the second user-group has produced very promising and encouraging results. These groups have included young adults with moderate learning difficulties but who are generally more mobile. Most noticeably, the issues outlined as a result of testing with the individuals from user-group one have not appeared to be as significant for those from user-group two. Individuals within these groups were allowed to simply try the instrument and improvise with the sounds as they wished. It has been rewarding to observe that users have been able to exhibit considerable independence whilst improvising with the system, although one key observation on this has been that it would be desirable to integrate a number of easily accessible switches that change one or two very basic settings e.g. type of sound and/or type of musical scale.

Users have also been observed trying to interact with the system in contrasting ways. For example, one user began by attempting a ‘tapping’ motion towards the sensors and then gradually adopted a more appropriate hand motion above the sensors. Another user, was using a gentle pushing movement towards the sensors which sometimes failed to trigger the sensor. Yet another, began at one end of the instrument with the sensors making a line perpendicular to their body, similar to the strings on a harp. Although the original design of the instrument had a particular style of gesture in mind it must now be observed that there are likely to be a number of alternate styles of interaction that might be more intuitive or, perhaps, physically less demanding depending on the abilities of the user. These are being observed and recorded during the close-observation sessions such that they can be compared and contrasted with one another in future designs.

Some users have also been observed moving their hands towards or away from sensors whilst a note is currently sounding; this is an apparent attempt to alter the character of the sound in some way. As identified earlier, the ability to dynamically change the loudness or tone of a sustained note can be a simple yet very expressive device. Although this feature is available within the system it is not yet a default setting. It seems that if the feature were to be made available in this way that it would be both instinctive and intuitive in operation. By placing an object into a ‘beam’ a sound is produced, if the object is then moved then the tone or volume of sound is affected to some degree. This is an aspect that will be explored further during follow up design phases.

Testing is also being carried out within a series of ongoing live improvised performances by users without specific needs. The aim here is simply to monitor how well the system performs (e.g. sensitivity, usability, reliability, interference etc.) within the context of specific performance activities. This has been particularly useful in terms of identifying a number of software ‘bugs’ but also in terms of assessing the impact of different lighting conditions on the reliability of the sensors in use. It is anticipated that all of these results will be greatly enhanced by the testing that involves individuals from user-group three.

5. FURTHER WORK

There are obvious issues with the shape and the layout of the current Benemin that need addressing before the instrument can be adequately reassessed with individuals from user-group one. The first is to reduce the height of the curve in the frame and the second is to reduce the width of the instrument’s span. Lowering the height will be relatively easy but this needs to be adjusted in relationship to the spacing of the sensors such that they do not interfere with one another. It is anticipated that this can probably be reduced significantly but there is also now a desire to maintain a level of curvature in the frame as this could be beneficial for users in wheelchairs. However, the base would need to be removed to maximise the flexibility that the curvature could provide in terms of positioning the instrument above a user’s lap. It may be possible to redesign the frame so that it is supported by an adjustable stand such that it can be set to different heights for different users.

There appears to be no immediate need to either increase or decrease the number of sensors available within the array for user-group two. Eight sensors allows many familiar musical scales and modes to be explored and this appears to contribute to the general appeal of the interaction. However, with user-group one, it would appear that fewer sensors could be less confusing and this would also reduce the overall span of the instrument. There are a number of possible solutions that are to be explored here. One would be to somehow make the instrument modular such that different numbers of sensors can be physically positioned and connected to suit individual needs. An alternate method would be to keep the general layout as eight sensors but to allow for individual sensors to be turned on or off. At its most extreme, this could mean that perhaps only one or two sensors might be set to be active and it might be that these are ones that most suit the type and level of movement that the user is most comfortable with.

6. CONCLUSION

Initial testing of the Benemin system has shown that the device has considerable potential as an accessible musical instrument for users with specific needs. However, this has mainly been observed whilst the device has been in use by users with moderate learning difficulties and marginally limited mobility. There have been indications that expressive control over individual notes would be used instinctively if the interaction by which this is achieved is intuitive to the user. Where users with severe learning difficulties were involved the layout and general shape of the device has been shown to require further consideration. The most significant issues recorded were with the height and width of the device and also the general robustness of the build. These are all aspects that can be significantly enhanced within a revised design and this is currently being addressed. A third user-group containing individuals where limited mobility is the prime consideration are still to be assessed with the device in its current form.

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SOUND=SPACE OPERA

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ABSTRACT

Over a period of three and a half months an artistic project using Rolf Gehlhaar’s SOUND=SPACE, was held at Casa da Música, Porto, Portugal, in the context of the meeting «*Ao Alcance de Todos*», with a group of young people with special needs. Two final performances were the public surface of a very rewarding process that improved the quality of life of those who participated.

1. INTRODUCTION

SOUND=SPACE *OPERA* was a challeging proposal made by Paulo Maria Rodrigues, Director of the Educational Service of Casa da Música to Ana Paula Almeida, Luis Miguel Girão, Maria Mónica and Paulo Neto. The goal was to run a series of creative workshops for several weeks with a group of disabled people and to present a final and public performance in that institution. The invitation happened in the context of the second edition of «Ao Alcance de Todos» («In Reach for All»), a meeting held on 15 – 19 April of 2008, that included workshops, performances and discussions about the contribution of technology to increase the accessibility of music, with resources that can give responses tailored to each individual, regardless of their capital gains or limitations. It was also intended to provide concrete opportunities to make music and to discover new forms of expression.

2. SOUND=SPACE AT CASA DA MÚSICA

2.1 Definition

SOUND=SPACE is an electronic musical ‘instrument’ ‘played’, by one or several persons at the same time, when they move around in an empty space, surveyed by an ultrasonic echolocation system (Ranging System). This system detects, with a high level of precision, positions and movement of bodies in space. The acquired data is sent to a computer that converts it into sounds. The typical physical space layout is normally square and measures from 6x6 m. to 10x10 m., sufficient for 8-15 people simultaneously. The ultrasonic ranging units are set up on two contiguous sides looking inwards across the space, creating a ‘grid’.

SOUND = SPACE came from an idea that Gehlhaar had in 1983, which envisioned the creation of a non-deterministic piece that ‘lived’ in a computer program and was ‘performed’ by its audience. People with no previous experience or musical expertise could make music in that space. The audience would become an active participant of the creative process, questioning the classic role and the *status quo* of the musical performer and composer.

2.2 *Musical Topologies*

A musical topology results from the analysis and processing of information gathered from the movement of bodies in a space equipped with sensors. The information is fed as control variables to compositional algorithms, that via synthesis routines, produces sounds.

These musical topologies - spatially distributed sounds or musical functions – can be either 'passive', 'active' or 'hybrid'. The first one, the most used at Casa da Música, is characterized by the triggering of a sound when someone steps into a precise area of the surveyed space. An active topology, in contrast, consists of an algorithmic composition being calculated in real time and 'performed' by the computer, but under the influence of the presence and activity (amount of movement) of persons in the space. The hybrid topology combines both of the above into a space that reacts not only to movement (in a nondeterministic or non-linear fashion) but also to position.

2.3 *SOUND=SPACE Workshops*

Since October 2008, SOUND = SPACE is installed on a permanent basis in the Orange Room at Casa da Música. The classical SOUND=SPACE system is running as an interactive installation. While in this mode it only uses 4 sensors. When workshops take place another 4 sensors are added in order to complete a double matrix set with a total of 8 sensors.

Numerous workshops have been run by Factor E - a group of specialized musical facilitators of the Educational Service -, addressed to the different publics, with and without musical expertise. These workshops are unique experiences of only 1 hour and 15 minutes, for groups, like school classes, associations and for anyone who wants to come individually. In the first case, we soon realized that it was impossible to have an ideal number of 10 to 15 participants attending the workshops, because, in Portugal, 28 is the average number of students in a class. This meant that to effectively carry out these workshops, it was necessary to increase the number of entries and, thus, have two facilitators per session. Half of the group was in SOUND = SPACE during half an hour, while the other half was in another area playing games using active listening and movement. After that, the groups exchanged. In the last 15 minutes, both groups met in the Orange room, observing each other's movements in space.

The workshops have a very flexible structure. Each group has its own dynamics, special skills and special needs. The process will always differ widely attending to the number of individuals and groups inscribed. Therefore, facilitators need a great deal of malleability and adjustment to specific situations. Objectives in the short and long term may be changed, reformulated or dropped as the interest and the concentration of individuals change or decline. This is perfectly understandable if we assume that SOUND=SPACE users are those who, by participating, drive and control the musical experience.

Although there is not a fixed script to run the S=S workshops, it is possible to describe some of the usual procedures of the facilitators. When a group arrives to the Orange Room, it is invited to cross SOUND=SPACE towards the place where they will sit down. As the 8 sensors are connected, sound (usually one of the Gehlhaar's topologies) is immediately produced.

Participants become very intrigued. Instead of explaining verbally what happened, one of the facilitators connects only one sensor and does a demonstration – a little "solo". Then he/she asks for a volunteer to move freely in space. After a moment of indecision, participants defy the inhibition and the evaluating look of their peers. It is normal to find someone reluctant to participate, and in that case we let them be seated observing others having fun. Like Gehlhaar once said, this is the best encouragement. We usually use the *Marimba Topology* because it gives a more accurate idea of the imaginary 'keyboards', enabling a better understanding of SOUND=SPACE. The laughter of the participants -that normally happens in this part of the session- is an important sign for the facilitators. It reflects their engagement and, also the transformation of this initial experience in something fun and relaxed. Soon, participants (one by one) want to be involved and to try out the sensed space.

When questioned, facilitators add more information about this musical 'instrument'. Then two volunteers are asked to be simultaneously in the space, and 2 sensors are connected. Usually, in this part of the workshop the ranging units become a very exciting object for the participants and the facilitators have to rethink their strategy. The visible part of the interactive environment tends to induce the movement rather than the musical content. When this happens the facilitators try to create an activity that will make participants concentrate only on the audible consequences of their movements. This interactive environment is for many of them the first opportunity to feel really powerful and to make loud and wild things happen without any disastrous consequences. Like Gehlhaar affirmed, this experience can be overwhelming, but the emotions they cause are an important aspect of the creative act.

Figure 1. *SOUND=SPACE setup at Casa da Música.*

During the workshop, facilitators would be moving from a particular mood to another (the marimba, more melodic, is alternated with for example more energetic rhythms), asking everyone to leave the area while changing the version and to return afterwards to play again the SOUND=SPACE. With this approach, and using very few words, facilitators encourage participation and concentration on the activity happening in that moment, in order to focus or shift attention of the participants.

Especially in the versions that are melodically rich, facilitators suggest a simple choreography. For example, with the 8 sensors all connected, 8 people are asked to move up one by one, each in its sensor. Gradually this semi-structured movement evolves to a free and chaotic movement and the rest of the participants join in the space. This is an activity that they enjoy very much, but it requires a high level of concentration on the sounds induced by body movements.

As the workshop follow, facilitators propose different ways of playing with SOUND=SPACE, not yet explored by the group, such as, to move in small and repetitive patterns, to cross the space very fast, to explore different forms of achieving silence, to do only one sound, to do what the other has done (mirror game), to create a set of musical movements in which everyone have to do according to a group sequence, and so forth. Usually, the session finishes with a free movement dance to the sound of, for example, House Music (another of Gehlhaar's topologies) with all participants in the space.

In this interactive environment there is not a wrong or a correct way to do it, we can only do it better. This is an experience where we can improve its quality. The structure of the topologies was built so that a movement more or less chaotic, disorganized and random by a group of people in space is transformed in a music flow that sounds elegant, planned and structured. The more variety there is in the movement when a participant "explores" the space, the greater the difference and diversity of music. Understanding how the space works is an advantage for "playing" it well. Furthermore, the participation is not only to be in space - sometimes alone but usually with the others - but is occasionally to sit and listen and observe the others.

SOUND = SPACE is essentially a social environment where interactivity happens and it is not limited to the interaction between person and "tool" but also includes, and perhaps more importantly, the interaction between person and person, while "playing" the environment. We should not forget that «interactive art focuses on interaction itself» (Fujihata, 2001). In an interactive environment such as S=S we realize that there is a real-time interaction between our actions and their consequences. We always have a truthful feedback of our choices and of the relationship with ourselves and with whom we share the space. Interactive art is not something that can be preserved as a document or as an artistic object. It is an event, something that takes place here and now, and that we make it happen. Nonetheless, those actions and interactions are embodied. They are imprinted into the memory of those who participated in the experience.

4. SOUND=SPACE OPERA PROJECT

4.1 Preparatory Phase

After the invitation of the Educational Service, facilitators chose as participants six young persons - João Pedro, Jorge, Alexandre, Catarina, Maria Lopes e Maria Ribeiro - mainly suffering from Down Syndrome- from the *Associação Somos Nós*, an association for the autonomy and the integration of young disabled people. This decision was taken because the group in question participated regularly, on their own initiative, in workshops at Casa da Música, always with enormous enthusiasm.

With a sense of continuity and unlike the unique experiences of the SOUND=SPACE workshops, this project was composed of seven morning sessions (1 h 30 min each), distributed between January and March 2008, two rehearsals and two public performances in April. Alongside, one of the facilitators worked weekly on the visual expression of participants in the room of the *Associação*.

After considering different approaches (for example, the narrative one) facilitators agreed to undertake a project that was an "open work" and consequently more focused on the creative process rather than on an evident public result. Without a pre-determined structure we left the participants *experience* to drive the creative process, in its different meanings (the knowledge gained in the course of our lives, our sense perception and the concept of experimentation). Although the title of the project appears to direct our attention towards the conventional musical genre of 'opera', our purpose was to create the opposite, i.e. an *opera* (Latin word for "work"), very informal and exploratory.

This decision was then communicated to the carer, the psychologist - the only carer that participated in the rehearsals and in the performance -, the drama and the visual art teachers of the *Associação*, who over the sessions were giving us some information about the special needs of each young participant.

The first contact of the three facilitators with the participants happened in a casual conversation, in which there was a sharing of musical tastes with the group as well as some trivial and funny episodes of their lives. After winning their trust, facilitators invited them to translate into sound (with and without words) and through movement some of those situations described. The other part of the session (45 min.) happened in the Orange Room, where participants tried SOUND=SPACE for the first time. As in the workshops, a flexible structure was used. After the initial minutes of some perplexity, there were some enthusiastic reactions and an evident sense of fun. Although this multifunctional system is complex, its non-invasive environment makes it uncomplicated, friendly transmitting confidence to users that were not even a bit intimidated. The fact that it does not require any musical knowledge, as a condition for the participant to create sounds and musical sequences, makes the all experience very exciting, engaging and pleasant.

At this stage of the project different versions of topologies were used, contrasting from one another in terms of their nature and mood (ethereal, earthy, abstract, recognisable, calming, exciting, lyrical, rhythmical, percussive, sustained, physical, strange, and so forth) and consequently suggested to the participants completely different movements.

S=S was first understood through the facilitators demonstration and by a brief verbal explanation. The interactive environment was thus gradually revealed through the exploratory movements of the participants. Once verbal communication was (almost) eliminated, body movement and expression became the main channel of communication. The major goal of the session was the free exploration of the creative possibilities either individually or through small groups, that acted simultaneously. Another aim was to focus upon the enjoyment of this experience, the empowering nature of the creative musical experience made available by SOUND = SPACE and the social interaction among the participants arising as a result.

The role of the facilitators was consciously passive, so that the participants could explore the space to the point of feeling comfortable and start to "play" spontaneously with the "instrument". Then we start to slowly introduce games to catalyze some movement forms that have not been carried out, and to discover some of the areas not yet explored. Those who understood, by listening, that their movements produced music, managed to explore different types of movement and became also the leaders of the group, while other participants were in a different stage of understanding.

4.2 SOUND=SPACE update at Casa da Música

In order to promote the creation of new material by both the facilitators of the workshops and the participants, Luis Miguel Girão developed and implemented an extension of the original SOUND=SPACE digital control system. SOUND=SPACE at Casa da Música is now a Laboratory for the Creation of New Musical Topologies.

Besides the Orange Room, another part of the public space of the building was used. In the Purple Room a temporary computer system was installed specifically for the workshops.

4.2.1 Technical description. The central part of the update made to SOUND=SPACE was the adding of a second computer to the system. This machine is installed in a moving stand in order to be easily put in and taken of the space. It has two video monitors: on the right hand side the participant can use a graphic simulator of the array of sensors, while on the left hand side monitor an instance of Ableton Live is running.

The simulator allows the user to test the position of sounds in the topology being created. This is achieved by moving the mouse on a top view of the array of sensors. When the mouse is over one of the division units, the correspondent sound is triggered. The user can choose to divide the ranging area of the sensors in 2, 4, 8 or 16 portions. Furthermore, a choice between testing 1, 2 or both layers of 4 arrays each, is also available. This program was written in Processing and communicates with Ableton Live via a MIDI internal bus. Ableton Live is a popular multi-track sound editor and sequencer for real-time applications.

When in use, this computer is connected via LAN network to one at the Orange Room, so that after creating their topologies the participants of the workshop can immediately try their creation in physical space.

In the Orange Room stands the classical SOUND=SPACE set-up with the exception of a new simple program that converts the data coming from S=S interface into standard MIDI messages. When SOUND=SPACE was built, Rolf Gehlhaar design it in a way that would allow the interface to use MIDI buses common to other instruments without taking one of the standard channels. The MIDI protocol allows only 16 channels per ‘cable’: by making the information provided by sensors to be communicated via a ‘negative’ MIDI channel, SOUND=SPACE could be integrated in a *through chain* without interfering with the other instruments. The problem is that the previously stated is not compatible with Ableton Live. A simple MAX/MSP patch was written in order to make the integration of Ableton Live in the new system.

4.2.2 Advantages of the update. The structural update made to SOUND=SPACE allows workshops for groups of about 25 participants to be held. The maximum number of participants playing SOUND=SPACE simultaneously is of about 5. As for the social and group interaction to happen, a number of about 12 participants is allowed. This means that users alternate in sharing the effective use of the instrument.

The second room makes it possible to double the number of participants. After a brief introduction, the group is divided in two, and while one of the groups is recording, manipulating sounds and finally put them together in the final topology, the others are playing with SOUND=SPACE and vice-versa.

The whole structure of the workshop also permits a better understanding of the system to the participants. To this, adds the creation of their own sounds which increases the engagement of the group. This feature is a very important one in the demystification of the processes of music creation. Music making becomes accessible to more people, including people with special needs.

4.3 Creative Process – “*translation of the day by day experiences*”

After the first session, the facilitators became more and more aware of the individual and collective idiosyncrasies. For example, João Pedro was always talking about his clarinet and doing mimetic movements related with playing that instrument. Catarina used recurrent movements of karate when she was trying SOUND=SPACE, and had always a football red card in her pocket that she would show us from time to time. When Maria spoke about “Dzrt” (a Portuguese pop band) her eyes sparkled and she would start dancing and singing forgetting about her equilibrium problems; Hip Hop was also the magic word for all the participants, who immediately embodied the attitude and style associated with that musical genre. Inevitably those significant actions and other meaningful events of their daily lives constituted the main vocabulary for the performance.

That decision drove us to the Purple Room. There, we recorded the sound material for the presentation. Different atmospheres and temperaments were registered, such as: funny episodes like an allergenic attack with sneezes (strange nose and cough sounds); restaurant sounds and the non noble eating sounds (chewing or burping); a football match with the screams of the fans in the stadium and the accusation of a fault, penalty or goal; the invention of a human beat box sequence; or the simple recording of the participants' names. The next step was to create the musical/sound topologies using the SOUND=SPACE simulator. As soon as the interaction between music/sound and movement was understood by all, the compositional process flowed and they could immediately and physically try the topologies previously tested in the simulator.

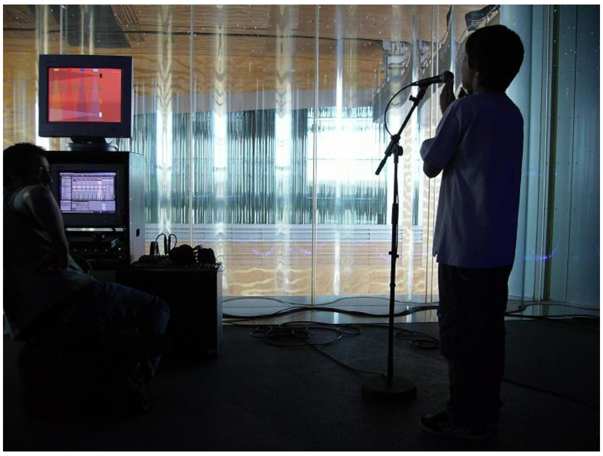

Figure 2. *S=S Simulator and Audio recording setup (Purple Room).*

Naturally, different choreographies arose from the work of the group. These semi-structured movements were gradually put in sequence giving origin to a performance scheme. Each one of these sequences answered questions such as "How can we *listen* to an inebriant perfume of a beautiful rose, or delight ourselves with the *musicality* of a delicious meal?" The background idea of these experiences is to promote the intersection of different perceptive channels.

The identification with the sound vocabulary and its associated movements produced a significant change in the behaviour participants. We could see them awakening, 'having an experience', as John Dewey once affirmed. Participants of this project took ownership of the environment, developing their creative autonomy and cooperation with their peers. At this point, SOUND=SPACE was «not an instrument that meant to be manipulated or mastered [but] an interactive environment that is meant to be experienced, and, if time and skills permit, to be explored and controlled» (Gehlhaar, 2007).

The facilitators could also observe other changes in the participants. During the first sessions, they were able to find that their positions and movements in space were inducing the generation of sound. They realised that sound was a 'feedback' of what they were doing. But when they became more aware, in terms of global perception, they realised that, in fact, sound also induced movement. From that moment on, their bodily expression, although autonomous and independent of external agents, was transformed: it became more controlled and structured. They began to adapt their movements in order to obtain what they wanted to hear. Now, the intentionality of their body movements controlled the sound produced.

The translation of significant day by day experiences into sounds and movements was the opportunity for the participants to express and relive the meaningful emotions associated with those events. "[The] significance must be sought in the capacity of movement, not to represent, but to generate the self" (Rick, 2001). This emerging self and the participants' direct control of the experience - without any apparent effort, but with an intense concentration and spontaneous attitude - made them merge with the environment. The sense of a self being separated from the world was lost. They "become one", and acquired an extended body. In this optimal and autotelic experience (flow) participants loose the conscience of self. Time is distorted and they do not expect anything else more than what they are experiencing - like enjoyment, fun, pleasure, fulfilment, autonomy and agency in life (Csikszentmihalyi, 1991).

From the beginning of the project, facilitators (with reduced experience of working with people with especial needs), had to rethink and readapt their behaviour. It was difficult for them to be quiet, just observe and listen to what participants were doing. They always had the impulse to help and guide, especially using verbal communication. After being confronted with the video recording of the first sessions, they understood the urgency of a non-directive approach. They also realised that the best facilitator is one that does not impose his own limits to others; someone who is a real person and not a mask; someone that puts the needs and interests of participants in first place; someone who dilutes himself in the group. As Lao Tzu once said, a leader is best when people barely know he exists.

The need to empower participants and to let them develop the necessary confidence to make their own musical choices, to decide their movements in space and to reinforce their identity without asking permission, was one of the initial goals of the facilitators.

The facilitators decided to include the carer throughout all the creative process, so that she could share the same experience as the rest of the group. As a collective, participants and carer could express, in a non-verbal manner, what they were feeling in a more freely, direct and embodied way. Cooperation overtook competition and helped the building of the social environment, and also to solidify relations in between the group.

Figure 3. *SOUND=SPACE OPERA (photos by João Messias).*

4.4 Performance

The final performances, preceded by two big rehearsals, were held on the 18th and the 19th of April, in Room 2 of Casa da Música. SOUND=SPACE OPERA was one of three projects of *INtermezzo*, among with *Sound Carousel* and *Digital Orchestra*. *INtermezzo* was a concert presenting results of the work developed by these groups. All of them included people with special needs. Two of the projects, had technology and interactivity as keywords.

In SOUND=SPACE OPERA, the only scenic objects on stage were sound objects. We thought that this would be truthful and coherent with the experiences lived by all. We all decided to wear a white monkey-hood to reinforce the idea of group, and to allow the projections of images onto our bodies. The audience was considered as another participant experiencing the sound movements of the participants on the stage.

The carer and one of the facilitators were always on stage. Facilitators alternated between them in order, either to be on stage, or to be operating the system.

What could be seen on stage was not a representation (extrinsic) but the expression of the collective inner self (intrinsic). It was something that has always been with the participants, and therefore belonged to them. They were just being themselves. Catarina's obsession with football, especially with the judge's red card, made her unexpectedly lead that part of the performance. This happened spontaneously without any external imposition. The same happened with other participants when they immediately started dancing Hip Hop as a strong beat was listened.

Two weeks after *Intermezzo*, when participants of SOUND-SPACE OPERA were asked to state what they enjoyed the most, Catarina said that she loved to be the judge in a football match, and the others to dance Hip Hop and sing. To the question: «Were you nervous?», João Pedro answered «No, no. It was normal». His answer meant a lot for the facilitators because it expressed the idea that the performance was something familiar and comfortable, confirming that the stage merged with his life.

We have found that the creative *process* of SOUND-SPACE OPERA was definitely the final *result*. Having a process as the final result, means that we are before something that is not static or passive, but dynamic and that will extend our experience beyond the workshops and the performances.

The global experience will dilute itself in participants' lives and will overcome all eventual barriers in time and space.

5. CONCLUSIONS

SOUND=SPACE OPERA revealed it self to be an intense process of self-discovering and interaction with the *other*. The translation of the significant events and the day by day experiences of the participants of this project into sounds and movements, made them relive and share those emotions on stage. They were not representing but expressing and exposing their emerging self. The interactive space became the stage where life and art blended.

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CaDaReMi – an educational interactive music game

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ABSTRACT

This new multi-user interactive sound installation (≤ 8 persons simultaneously) implements proprietary glob-recognition and tracking software in order to allow visitors to a large empty space (~5m × 7m) to move an avatar – projected on a screen at the end of the space – simply by moving about the space, with the objective of taking it to specific, recognizable locations. Success in this endeavor causes sounds to be triggered.

1. BACKGROUND

In 1984 Rolf Gehlhaar developed SOUND=SPACE (1), an interactive multi-user musical environment in which visitors trigger and influence the production of sounds merely by moving about an empty space surveyed by an ultrasonic echolocation system. Since its development it has been displayed publicly worldwide, becoming a particular favourite with special needs groups primarily because it makes creative musical expression accessible to persons generally excluded. SOUND=SPACE is still being explored by visitors and participants in creative workshops for special needs groups. At the time of writing one of the systems is installed 'permanently' in Casa da Musica, Porto, Portugal, where workshops for special needs groups are taking place weekly.

Some of the many lessons we have learnt from SOUND=SPACE installations and workshops with special needs groups is that, if a multi-user installation is to make justifiable claims to being educational, several criteria must be met: How to use the installation must become clear upon only a brief exposure to it and gradually 'intuitive', i.e. with very little explanations required. Users must be able to understand the 'sound topology' (the spatial distribution of the sounds and the locations of the functions of control). The installation must be so fashioned that it is possible to get better at using it. Ideally, it should possible for 5–8 people to use it simultaneously with each user still being able to understand what it is they are doing individually, how they are contributing to the global sound.

Because in SOUND=SPACE there is practically no visual information about where the sounds are located, one of the problems we have experienced is that it is quite difficult for users to 'anchor' their activities spatially. In order to achieve some mastery, SOUND=SPACE demands fairly intense listening skills with considerable attention paid to the sounds, so that the users can relate different sounds to different locations in the space, different gestures to different effects.

2. AIMS & OBJECTIVES

CaDaReMi addresses this problem by providing a number of visual clues designed to help the user understand 'how things work', to use the 'spectacle' of the installations to 'explain' it to new users and to make the sound topologies visible. Beyond this, the following aims and objectives remain:

- To be entertaining and provide a stimulus for users to explore expressively a wide range of different sounds;

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- To be collaborative: it may be used by several persons (up to as many as 8) at the same time;
- To be sonically challenging and interesting, providing a palette of both familiar and strange sounds;
- To be visually engaging, enhancing the users' experiences and promoting their ability to locate themselves and to decode the events of others in the space at the same time;
- To be socially engaging by promoting user-user interaction, thus strengthening the sense of community of activity and place;
- To be intuitive in its functionality and use, with no explanations required and no expertise in order to get 'first results'.
- To be learnable and masterable: sufficiently complex that users may, in time, enjoy the experience of "getting better" at using it; but, at the same time, sufficiently easy that beginners may quickly experience success.

3. THE STRUCTURE AND PROCESS OF *CaDaReMi*

An overhead digital infrared camera, whose images are processed by a proprietary glob-recognition and tracking program, monitors the empty horizontal space of the installation, approximately 5m × 7m. The space is semi-dark, illuminated only by the reflected light from a large screen, c. 4m × 4m, at the long end of the room. When the space is empty a projection consisting of distinctive opaque black, rounded, angular and sharp profiles against a light grey background (see Figure 1). These profiles never change shape.

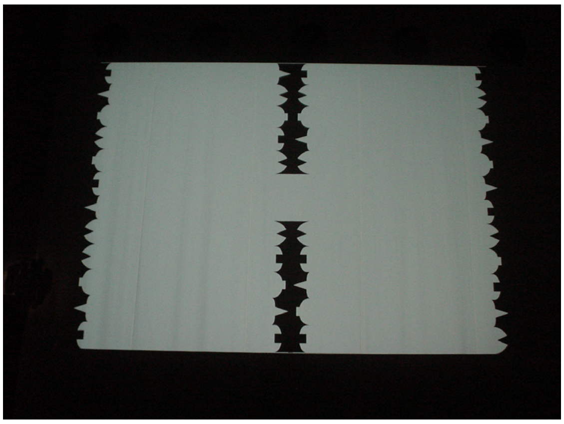

Figure 1. *The empty space.*

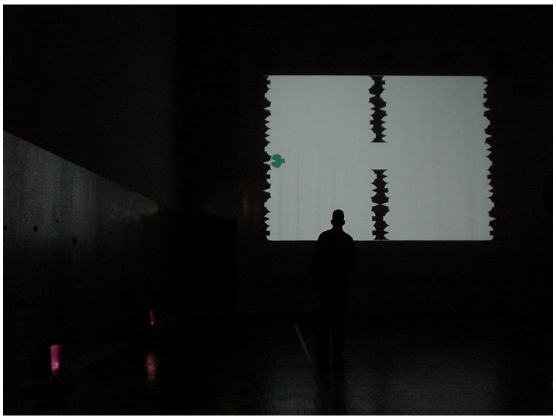

Figure 2. *A single player.*

The mere presence of a visitor in the space surveyed by the infrared camera causes the recognition program to generate and project a virtual 'object' into this landscape of profiles, an avatar of the located user that follows her about as she moves (see Figure 2). Simultaneous with the appearance of the distinctively shaped avatar appears, a specific sound is triggered. This individual sound, which we will refer to as the *name* of the avatar, is attached to every avatar and is only triggered only once, when the avatar first becomes visible. An avatar never changes shape, only its position on the screen and its colour. Whenever a user leaves the space, his/her avatar disappears. When a user enters the space again, a new avatar is generated, a new name is 'called'.

The left and right profiles of the avatar clearly suggest that they bear some relation to the landscape of profiles, demanding to be explored with the avatar. By moving in the space the visitors may move their avatar: moving right/left moves the avatar right/left, moving towards the screen moves the avatar down, moving away from the screen moves the avatar up. Access to the space is restricted to the far and of the space; hence all avatars enter the landscape of profiles at its top. Whenever a visitor moves her avatar (see Figures 3 & 4) to any one of these projected profiles whose shape will 'fit' the avatar, the avatar blinks and a sound specific to that 'object' is emitted. The metaphor here is that of *lock* (profile) and *key* (avatar). For the sake of simplicity, they will be referred to as such in the following.

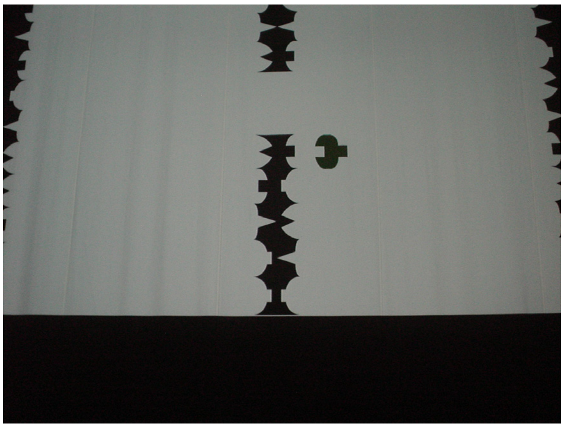

Figure 3. A key approaches a lock.

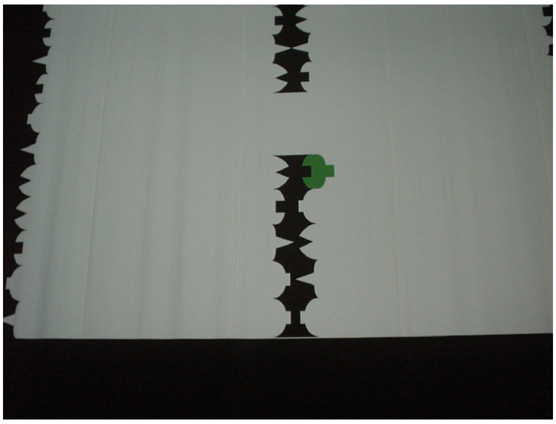

Figure 4. The key fits & blinks.

A further important function of the installation is that players may also 'fit' their keys to each other (see Figures 5 & 6). The profiles of the keys may also function as locks for other keys. With only 2–3 players in the space, there is no guarantee that there will be a key that fits another but as the number of players increases the probability steadily increases. When two keys are fit a sequence of sounds is emitted: the names of the avatars mentioned above. The two names are 'called' repeatedly, one after the other, as long as the fit is maintained. This function, extrapolated from experience gathered by one of the authors (Gehlhaar) in workshops with *SOUND=SPACE, is* primarily designed to engender a sense of community, to encourage cooperation and promote the spontaneous creation of 'close' encounters within the space, which can often result in many quite humorous 'entanglements'.

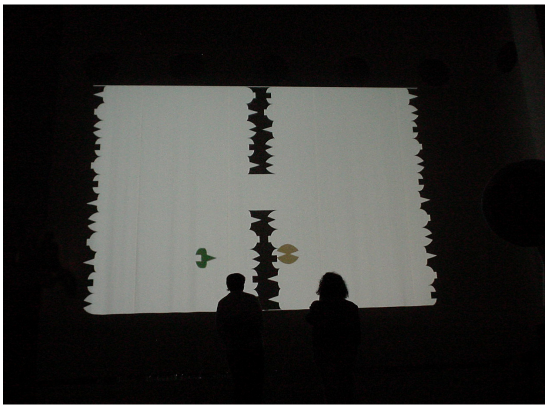

Figure 5. Two players.

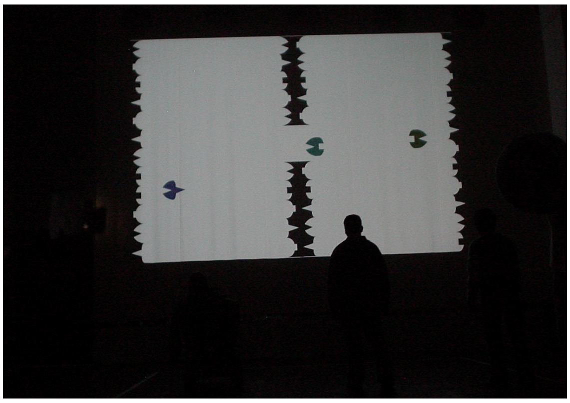

Figure 6. Three players.

The maximum number of different locks and keys possible (and required for multi-user applications) is determined by several factors: the focal length of the camera, the height of the camera, the resolution of the projector, the size of the person whose glob is being recognized and converted into an avatar, the desirable minimum number of different keys and the desirable minimum number of locks available to every key. In this version these factors interacted to allow for a total of 44 locks, 22 of four different left-hand profiles and 22 of four different right-hand profiles, with a maximum number of 16 different keys (four different *left* profiles × four different *right* profiles). Every time the program is executed a different combination of locks is generated. Similarly, every time a person enters (or re-enters) the space a different key is generated for them. Each key fits and average of 5–7 left hand locks and 5–7 right-hand locks, resulting in an average total of 10–14 different sounds available to a player.

The structure of the software developed for *CaDaReMi* is composed of two programs that run simultaneously in the same computer and communicate between them via network packets. One of them is dedicated to video capture and position analysis based on glob distinction techniques. The other is dedicated to the audiovisual outputs – graphic symbols and associated sounds. This solution allows future applications that only use one of the programs and makes the development and implementation of newer versions of each one of them easier to. Furthermore, this solution already opens doors for the development of multi-post and multi-location versions of *CaDaReMi*. In this phase, all software was written in Processing, an open source multi-platform programming environment. Therefore, the software of *CaDaReMi* can run in several different types of computers, running different operating systems.

The process of calibration of the system, which is normally one of the biggest problems in this type of installation, is very simple and reduced. All image analysis is done after a background subtraction process which simplifies immensely the distinction processes. This, combined with the fact that all images analyzed are in the infra-red range, also reduces the possibility of interference from other light sources. The only parameters to be adjusted for each iteration of this installation – all in the program that generates the audiovisual output − are the ones concerning the size of the space being used, the camera and the projection system. That is, scale factors need to be determined in order to establish a even relationship between the size of the image captured by the camera and the size of the projected 'avatar' (key).

This location and glob-recognition interface developed by us (Girao & Gehlhaar) for *CaDaReMi* is generic and will be used for any number of different activities and 'games', some of which may not necessarily be directed towards the creation and manipulation of sound.

4. FIRST INSTALLATION IN CASA DA MÚSICA, APRIL 2008

The first installation of *CaDaReMi* took place during the month of April, 2008 as a part of the programme 'Ao Alcance de Todos' (*Accessible to Everyone*) devised and programmed by one of the authors (Rodrigues). The Education Service at Casa da Música (CdM) organizes a broad range of regular activities and throughout the year many people with disability come to CdM to participate in workshops or to attend concerts. A number of medium term creative projects with disabled people at Casa da Música are also organized and there is a special program (A Casa vai casa) that allows institutions to request CdM educators to come to their facilities and develop short term projects on site. It is, however, during one week in April that the issue of music and disability receives a particular focus with 'Ao Alcance de Todos'. Specific workshops, conferences, concerts, showcases and debates focusing on Music, Technology and Special Needs are presented at this time, offering an opportunity that institutions dealing with special needs usually rapidly subscribe to.

In the case of *CaDaReMi,* five schools for special needs students responded to an invitation to send a group to participate in a 1½ hour-long workshop. The workshops, held in the morning and afternoon of three consecutive days, were facilitated by two of the authors (Gehlhaar & Girao), as well as accompanied by at least two teachers from the respective school and one or two observers. Dr. Eva Petersson of Aalborg University, Denmark, was invited by Casa da Musica to carry out a professional evaluation. The profile of the groups attending the workshops was varied: each consisted of 12−20 students of similar ages (11−20 yrs), all primarily with pronounced learning difficulties. Each group also encompassed two or three wheelchair-bound participants. Overall, their social skills within their group were, however, typical of what one would expect of any young persons of that age**.**

All of the workshops were organised along similar lines: each began with a short verbal introduction, explaining only that the workshop was about playing with sounds. This was followed by a quick demonstration: one of the facilitators enters the space, a *name* sound is triggered, and then he gradually moves his key to one of the locks, producing another sound. Usually this was repeated once or twice. And then participants of the workshop were invited one by one to try it out for themselves. Once everyone had tried it out alone, they were invited to 'play' together, two, three or four at the same time.

5. EVALUATION

The evaluation of the installation and the workshops was carried out in two ways: observation and the questionnaire circulated among the participants after the workshop. In some instances the questionnaires were completed for the student in consultation with the teacher. These questionnaires were taken for an evaluation by Dr Eva Petersson **(**Assistant Professor, Aalborg University, Department 7, 6700 Esbjerg, Denmark), who will be publishing her findings next year.

Beyond our aims and objectives for the installation that it should be a pleasurable, social experience, as outlined above, we also expected a variety of learning outcomes. The first of these were that the players of *CaDaReMi* would readily, without any explanation, understand the affordances of the installation, that they would develop an awareness of the concept of sound topologies and that they would improve their performance within a short time.

The influence of the accompanying teachers on the success of the activities in the space was notable. Some of the teachers just sit back and relax, seemingly delighted to be relieved of their usual responsibilities for a short time; others seek to maintain control, sometimes discouraging exploration thereby; others join in and act as a fabulous catalysts for play and learning. In this way, the teachers at special schools seem to be very little different from teachers at other schools.

It was quite clear that, after the first demonstration, everyone completely understood the main metaphor and the affordances of the installation, as well as the directional correspondences between movement of self and movement of the key on the screen. Most of them were able quickly to identify a lock that would fit their key and then promptly decide to manoeuvre it there.

The main activity in the space – moving the key to its intended lock – is not without its difficulties. Control over its movement must be practiced a little. The tendency for the beginner is to move too fast or too far in the intended direction, resulting in the key crashing into the sides and getting stuck. As there is no haptic feedback, the player must develop a sense of the time it takes the computer to react to the movement of the player, how long it takes to move the key as well the relationship between the amount of movement of the body in real space and the amount of movement of the key in the projected space.

Because of this level of difficulty, success sometimes took more than a minute. Some participants were not even successful after several attempts, notwithstanding the frequent shouts of directions and encouragement from their fellow students all the while. However, no one finished their turn completely frustrated; it just took a bit longer.

As a result, the sound arising from a fit tended to be considered a reward for success rather than the main objective. Although the participants always applauded a success, demonstrating their participation in this social activity, this level of difficulty was not intended. Our intention was that, because of the visual referent, it would be relatively easy to trigger sounds. We clearly need to find a different compromise between accuracy of a person's control over their key and the accuracy of creating a match. However, after several attempts, many participants were able to improve their performance, to trigger a sound fairly quickly and repeatedly, a significant measure of the effectiveness of the installation as a creative and learning environment. Responses to questionnaire clearly indicated that the vast majority of the students wanted to do it again and have more time at it.

There is no question as to whether the 'lock and key' feature contributes to the development of spatial awareness and abstract conception of space: this is primarily evidenced by the fact that all players took great pleasure in simply moving their key about the space, even if they (only very few) were a little annoyed by not being able to fit a lock at the first attempt). But this annoyance did not stop them from continuing. As the players developed an increasing awareness of the correspondences between the real and the virtual space − something that is, we believe, becoming of increasing importance for everyone, able-bodied as well as disabled − they developed greater sensitivity of control and greater accuracy of movement. Thus, as long as there is no frustration, the hope for success remains alive. In any case, players are likely to have seen others succeed before taking their own turn.

6. CONCLUSIONS

6.1 How well did we meet our aims?

It was among our intentions:

- to create an entertaining environment which will stimulate users to explore expressively a wide range of sonically challenging and interesting sounds.

This aim was met with varying degrees of success: The visitors enjoyed the workshops immensely. The installation was accessible to all, everyone quickly understood the metaphor and the affordances and could immediately attempt to trigger sounds. Everyone was thoroughly stimulated, equally by being an actor in the space and a viewer. However, the degree of difficulty of successfully navigating the key into a position that would trigger a sound was higher than expected. It demanded almost total concentration, especially when there were two or more players in the space. As a result, the density of sound was less infrequent than expected. Even when there were 3−4 players in the space simultaneously, the density of sound was still quite low. However, they loved the sounds. These consisted mainly of slightly modified and extended percussion samples, each with its own distinct timbral and rhythmic 'personality'.

- to create a multi-user collaborative creative space and to provide a socially engaging experience that promotes user-user interaction strengthening the sense of community of activity and place.

This aim was also met with partial success: the exertions of the players in the space always received positive vocal support from the 'audience' (players-in-waiting). This is, however, only one aspect of a collaborative space; the other is players in the space actually interacting to create something they could not do alone. Due to the level of difficulty mentioned above, this type of interaction was limited to the occasional rare moment. Furthermore, the difficulty experienced in the maneuvering one's key was increased by the presence of the players in the space as some players became aware of being crowded; they actually preferred to be the sole user of the space, a solo player as it were.

- to create an activity visually engaging, enhancing the players' experiences and promoting their ability to locate themselves and to decode the events of others in the space at the same time.

In this we were entirely successful. Many of the visitors expressed joy in being able almost effortlessly to move their key about the screen even if precise control was a little difficult. Some players liked to move across the 'threshold' in to the space, see their key appear, hear their sound, only to step back out and to repeat the process again and again.

6.2 What improvements are required?

It is, at first attempt, quite difficult to manoeuvre one's key into a lock; it is even more difficult for first time users with combined learning and mild physical difficulties. In the first instance, we want the installation to provide and incentive for people to play and create with sounds. Therefore it needs to be learnable and masterable: to be sufficiently complex that players may, in time, enjoy the experience of "getting better" at using it, but, at the same time, sufficiently easy that beginners may quickly experience some success. In order achieve this, we clearly need to find a way to adjust its level of difficulty. Perhaps a way forward here is to define an 'automatic acceptance zone' of a fixed number of pixels around each lock. Once a key is within this zone, it automatically 'pops' into place and triggers the sound. This will facilitate the triggering of sounds.

Another improvement that must be considered is a diminution of the difficulty encountered by a wheelchair player, alone or being pushed around the space. There are two main problems: 1. The wheelchair appears as a rather large glob, something which interferes with the accuracy of movement, particularly at the moment of the fit. 2. If a person is pushing the wheelchair their glob often separates itself from the player, spontaneously creating a new key; this confuses the system. Again, some means of adjusting the level of difficulty could solve this problem., for example by making the correspondences between glob size, key size and lock size easily – in real time – adjustable. We believe with some small adjustments in this domain of the software, the environment will succeed in fully delivering the wealth of highly enjoyable creative resources that it promises.

Due to other inadequacies of the software, related to the one discussed above, which we were not able to resolve due to lack of time, we were not able properly to evaluate the contribution of the key-to-key feature to the strengthening of social interaction in the space. The key-to-key interaction presents a particularly knotty software problem because the key (a virtual object) is a representation of a real object (the body) in real space. In order to fit the keys to one another, the bodies – the globs from which they derive their existence − must collide. When the globs collide they lose their identity. In order to solve this problem, we must carry out a fundamental revision of the recognition/avatar generation process. One way forward would be to make the avatars larger than the blob in the vertical dimension and to use the top and bottom profiles for defining a fit. We are currently working on this.

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Making music with images: interactive audiovisual performance systems for the deaf

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ABSTRACT

This paper describes the technical and aesthetic approach utilised for the development of an interactive audiovisual performance system designed specifically for use by children with multiple learning difficulties, including deafness and autism. Sound is transformed in real-time through the implementation of a Fast Fourier Transform (FFT) and translated into a moving image. This image is adapted so that relevant information can be understood and manipulated visually in real-time. Finally, the image is turned back into sound with only minimal delay. The translation process is based on research in computer music, neuroscience, perception and abstract film studies, supported by the Arts and Humanities Research Council. The system has been developed through collaboration with the Sonic Arts Network, Whitefields Special Needs School, and the South Bank Centre, specifically for a project led by Duncan Chapman with the London Philharmonic Orchestra. The system has now been made available for free by the Sonic Arts Network.

1. INTRODUCTION

Through collaboration with the Sonic Arts Network, Whitefields Special Needs School, the South Bank Centre and the London Philharmonic Orchestra, a software system has been developed that visualises sound in real-time in a way that allows hearing-impaired individuals to interact with a specifically designed, experiential representation of sound.

Deaf children with learning disabilities can interact with the system through the use of a Nintendo Wiiremote, which provides additional vibration-based feedback when the audio signal peaks over a set amplitude. Users can load and play back sounds from the remote, whilst using the accelerometer to make real-time adjustments to the pitch, pan position and volume. In addition, the system accepts live input, giving users the ability to interact with musicians in a meaningful way, either by changing the nature of the sound in real-time, or by recording and playing back segments of live audio. Beyond this, the musical output of the software can be set to a number of transposable scale systems. This allows for a wide range of musical interaction.

Musical interaction is conducted through the alteration of the visualisation itself. Through learning to control a number of specific gestures, the users can alter the appearance of the visualisation instantaneously. The visualisation is then converted back into audible sound, perceptually occurring at the same time as the original sonic material. The sound and music is effectively 'translated' into useful visual information that can be sensibly interpreted and changed in real-time by users who are unable to easily hear and react to the sound itself. Most significantly, the system allows for users to become more aware of their own sound making in an informative, detailed, and immediate way, providing useful information that could aid in the development of a user's relationship with sounds. It is hoped that this system will have genuine therapeutic benefits for those without normal hearing, particularly in relation to the development of voice production.

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2. THE VISUAL REPRESENTATION OF SOUND

2.1 Existing Standards for Sound Visualisation

Several standardised methods for visual representation of sound are used everyday by musicians, engineers, and others that need them. These methods can be loosely divided into three types: Symbolic representation, average level indication, and spectral analysis.

Symbolic representations, such as musical scores, graphic notations and markup languages display information using an agreed set of symbols. These forms of representation only convey a certain amount of information, given a specific set of limitations. Most importantly, their relationship to sound is not indexical (in the sense of Peirce (in Hartshorne et al, 1931-58)) - i.e. the sounds and images are not in 1:1 relationships.

Level indicators such as PPM (Peak Program Meters), VU (Volume Unit) and dB (decibel) meters display changes in the average amplitude of sound signals. These are less like symbolic representations in that their relationship to sound is indexical. However, the amount of sonic information contained in these displays is limited. Information is only apparent in one dimension – amplitude. For example, it can be considered impossible to discern pitch relationships by viewing a level meter.

Spectral analysis is a robust method for sound visualisation. Spectrographs & sonograms function by decomposing sounds into a number of component sinusoids, and plotting their amplitudes on a graph. This is usually performed using a Fourier Transform, although other (related) methods exist.

In the case of providing visualisations for those with disabilities for the purpose of interaction, all of these methods could be improved, either lacking in sufficient information, or being difficult to understand. Symbolic representations often contain little textural or experiential information – that is to say, symbolic methods can be used to describe how a sound changes over time, and what pitches it might contain, but not what it is like to hear the sound. Level meters provide some experiential information, but this is heavily limited. Spectral methods provide a great deal of information with respect to the power spectrum of sounds – but this information is not presented in a way which makes it easily understandable, nor experientially relevant.

2.2 Audio Visualisation in Experimental Film

Within the discipline of experimental film there have been many highly regarded attempts to visualise sound and music in ways that are experientially relevant. Key examples of this practice include *Rhythmus 21* (Richter, 1921), *Diagonal Symphony* (Eggeling, 1922-24), *Studie No. 6,* (Fischinger, 1930), *Allegro* (McLaren, 1939) and *A Colour Box* (Lye, 1935). To some extent, information about sound is translated into moment-to-moment changes in shape and texture in an attempt to echo the experience of sound. An excellent example of this practice can be found in the work of John and James Whitney, notably *5 Abstract Film Exercises,* (Whitney, 1944-45). These practices have been well documented by scholars such as Al Rees (1999), P. Adams Sitney (1974), and Malcolm Le Grice (1977), among many others.

Importantly, these relationships can easily be shown to be arbitrary, containing little or no musical or detailed sonic information (similar to symbolic and level indication methods, whilst sometimes containing textural information). Despite this, what is key about this practice is that it emerges from the idea that elements of our sonic experience – specifically in terms of motion - can be experienced visually. As Sitney mentioned on the occasion of film-maker Stan Brakhage's death (Sitney, 2003), Brakhage was committed to the concept of 'moving visual thinking', the idea that internal cognitive visual processes could be made visible. Even though Brakhage had often discussed his practice as being related to music, there is a tension here between the desire to explore purely visual processes, and the concept that vision can be similar to musical experience. However, through this tension rises potential new solutions to the problem of how to effectively represent sound for the purposes of audiovisual interaction, particularly in situations where participants have a very different experience of sound.

3. NEUROSCIENTIFIC EVIDENCE FOR THE EFFECTIVENESS OF AUDIOVISUAL CONGRUENCE

Evidence supporting the view of experimental film-makers that the experience of sounds and music can be fundamentally linked with the experience of moving images continues to grow. Key examples demonstrating the stimulation of multisensory cells in the Superior Colliculus by audiovisual interaction include the McGurk effect (McGurk et al, 1976), and the double-flash illusion (Shams et al, 2000). In addition, evidence that seemingly arbitrary links between sound and image can improve event perception is emerging (Effenberg, 2001). The idea that a visualisation based on perceptual congruence may aid in translating the experience of sound for non-hearing populations has not been effectively tested, and there may be several problems with this view – especially considering that the precise nature of audiovisual relationships often appears arbitrary and is not always well understood.

Our research does not necessarily claim to have scientifically demonstrated a definitive link between a particular type of visualisation and a particular type of sound. Instead, we offer a technically useful and experientially relevant method for translating sound to an image and back again that may prove to be effective for enhancing musical and sonic interaction, particularly (but not exclusively) for the deaf and hard of hearing. Most importantly, we have chosen a visualisation technique directly inspired by experimental film practice, and neuroscientific enquiry that directly relates to the structure of the visual cortex (Bressloff et al, 2001).

4. METHOD

This project combines experiential approaches that share similarities with symbolic and indexical forms of audio visualisation (such as those found in experimental film making practice), with filtered spectral analysis and signal processing methods (FFT and related processes). This introduces a level of information not commonly found in similar approaches. Importantly, not all the available spectral information is used in the visualisation. Attempts have been made to reduce the amount of information so that only the most important elements are retained. Once the sound has been translated into image, it can be manipulated in real-time by a user. Importantly, the manipulated image can then be turned back into sound. This process occurs quickly enough that the users remain unaware of any significant time delay. Crucially, it is the real-time editing of this image which results in the perceptually relevant changes in the sound.

4.1 System Design and Aesthetics

The project was realised using Cycling 74's Max/MSP/Jitter, based on Miller S Puckette's Patching environment (Puckette, 1988). The sound is converted into a real-time spectrogram (see Figure 1). This spectrogram is loaded into a one-dimensional 32 bit floating point array, 2048 bins in size (see Figure 2.). It is then modified to appear as a set of two-dimensional concentric rings. In order to preserve processor load, the calculation from one to two dimensions is done using the computer's video hardware. This is achieved using a texture mapping process, with the one dimensional array being stretched across an OpenGL Surface. The OpenGL surface can be manipulated using a third dimension, to alter the appearance of the concentric ring formation with very limited CPU overhead.

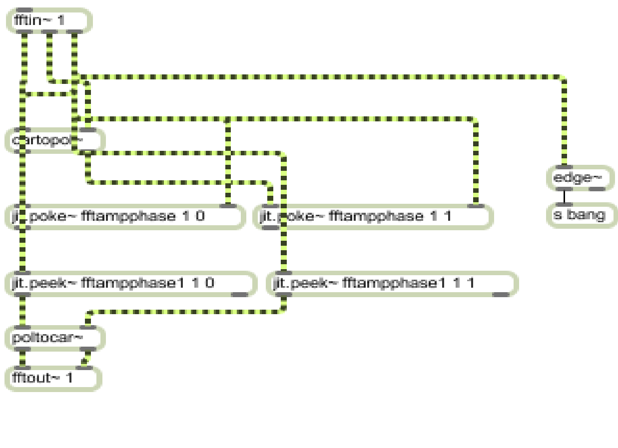

Figure 1. *Max/MSP Patch showing an FFT process being sent to a video buffer.*

This results in an additional speed gain, and is useful for filtering the visual information without altering the material in the video buffer itself. This means that the image can be made more perceptually relevant without losing valuable data that is needed in order to re-synthesise the signal. Most importantly, all data manipulation continues to be performed on the one dimensional array, whilst being displayed in three dimensions.

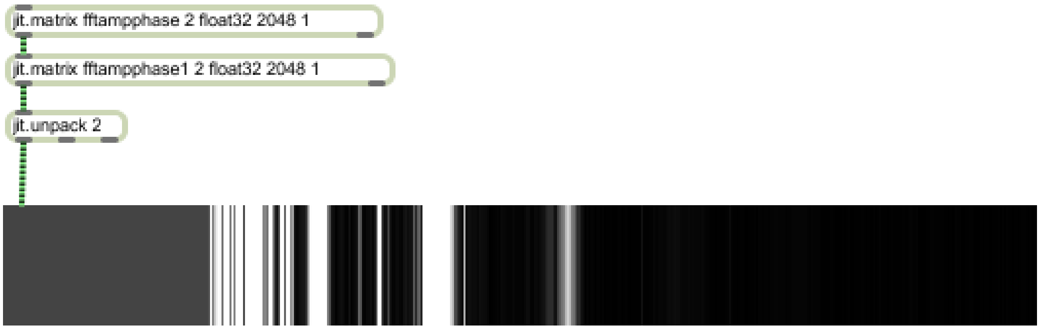

Figure 2. *The FFT data expressed as one dimensional video information*

The concentric rings are spaced non-linearly so as to more accurately mirror human perception of audible frequencies. The exact spacing of the rings is achieved through the application of a logarithmic function on the visualisation of the 2048 point FFT spectrum. This function is applied by mapping the information onto a 3D OpenGL sphere (with non-uniform dimensions). This results in some spectral information loss with respect to the display. This is acceptable for two reasons. First, the spectral information is still maintained in the one dimensional array. The shifting in pitch appears relative, whereas if the display were linear, the shifting would appear to spread out as the fundamental frequency rose. Secondly, it is not required that the display be scientifically accurate, just that it remains perceptually relevant, whilst still resulting in an accurate re-translation back into sound.

4.2 The Concentric Ring Formation as a Form Constant

There is a precedent for the representation of sound and music in a concentric ring formation that is clearly demonstrated in the field of early 20th century film making and animation, such as the visual music tradition. Oskar Fischinger's silent film *Spiralen* (Fischinger, 1924) uses a number of concentric and spiral formations in what can be described as an early attempt at producing a visual metaphor for the experience of sound. In addition, this type of representation is echoed in the work of computer graphics and visual music pioneer, John Whitney. Although neither of these artists exclusively used the concentric formation, the iterative tunnel effect which it produces fits with the forms that continually appear in this canon.

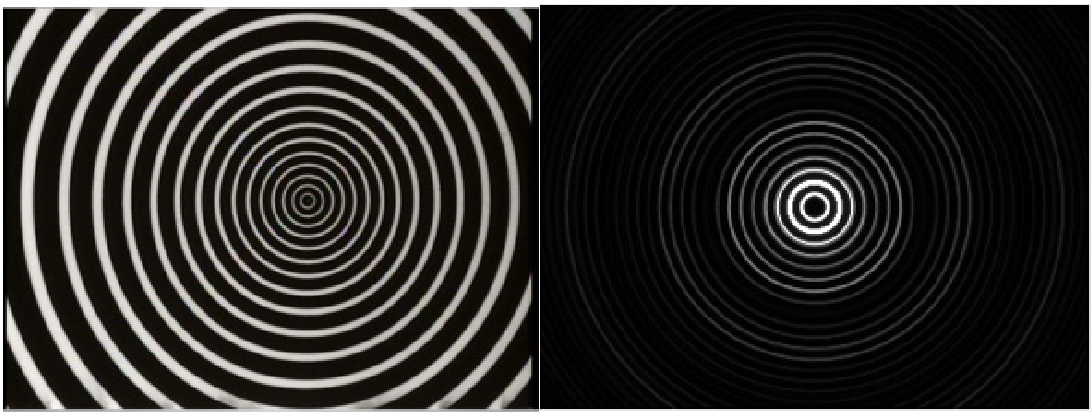

Figure 3. *Still image from Spiralen (1924) by Oskar Fischinger (left), and a screengrab from the audiovisualisation software (right).*

Further reasoning behind this choice of visualisation comes from studies in neuroscience and perception. In Bresslof, P., et al (2001) a number of visual patterns are identified as persisting in various forms of visual art and experience generally as a result of their direct mathematical relationship with the structure of the visual cortex. These visual configurations are roughly divided into four categories - tunnels and funnels, spirals, lattices (which include honeycombs and triangles), and cobwebs. The formation described here fits more than one of these categories at various times depending on the nature of the sound being analysed / re-synthesised. However, due to the perspective illusion that it evokes, it most closely fits within Bresslof et al's 'Tunnels and Funnels' category.

These precedents provide theoretical weight to the idea that a very specific type of concentric visualisation may be effective with respect to the goals of the project. The Concentric ring display format was chosen in an attempt to encourage the users, most of whom were autistic in this case, to focus on the image as a focal point of their experience, and to become sensitive to the complex and potentially delicate variations in the sound that result from the user altering the image through their own interaction. It is also being employed to hold their attention, and to give them an indication of the morphology of the sound and music that other, able bodied participants are experiencing.

Sonic transformations are performed by moving the FFT bins in both directions. These bin shifts are logarithmic – frequency relationships remain coherent throughout musical octaves. In addition, phase information is rotated, enabling the system to operate as a phase vocoder. As such it provides smooth real-time pitch correction, and can be used as a high quality real-time time-stretching device. In addition, the system allows for spectral freezing and Fourier synthesis through manipulation of frozen spectral fragments.

5. RESULTS

Working alongside the Sonic Arts Network, Whitefields school, and in collaboration with experienced workshop leader, Duncan Chapman, various versions of the software were tested with a number of users. Feedback was very positive with respect to the effectiveness of the visualisation. Immediately it became apparent that the software gave children with multiple learning disabilities including deafness the opportunity to appreciate the way their own sound making was experienced by others. Through comparing the experience of 'video-listening' to pre-recorded and live sound material with the experience of their own interaction and sound making activity, users were able to more effectively appreciate the effects of sound in the world around them. As such, the tool was considered immediately useful in (re)habilitation, giving non-hearing users a simple way of having meaningful relationships with sound and music.

Two significant problems were identified and overcome throughout the testing period. First, the system allowed for non-hearing individuals to synthesise sounds through a visualised form of Fourier synthesis. It was found that although this could be entertaining, it often produced a wide variety of unpleasant sounds. These functions were disabled, although they may be added again later as the control functions become increasingly refined. In addition, it was noted that the graphical interface could be developed to enable teachers and students to use the system unaided by the workshop leader. As a result of this process, a GUI was designed through collaboration with an information designer with knowledge of teaching environments (Figure 4).

A later session, organised and filmed by BBC online technology at the Frank Barnes School for the Deaf, showed that the system could be successfully used by students and staff with little difficulty. In addition, this session demonstrated the system's capacity for use in voice production training. Through focussing on the image, students were able to respond to very small changes in the sounds that they were producing. As students began producing sounds, they appeared immediately aware of the way changes in a sound's tone and quality were being represented. This seemed successful in that students were able to easily begin to produce similar sounds by watching the variations on the display, and attempting to repeat sounds reliably. Staff at the Frank Barnes school were confident that the tool could be of great benefit to many with respect to voice training. As a result, plans are being made to deploy the software throughout a network of deaf schools in the UK.

Finally, Duncan Chapman has developed a set of workshop exercises that can be used as a starting point for those wishing to use the system. These cover three main areas: voice production, recording and playback, and musical interaction with other performers. The workshop exercises are distributed as part of the download package, which can be found at www.sonicartsnetwork.org.

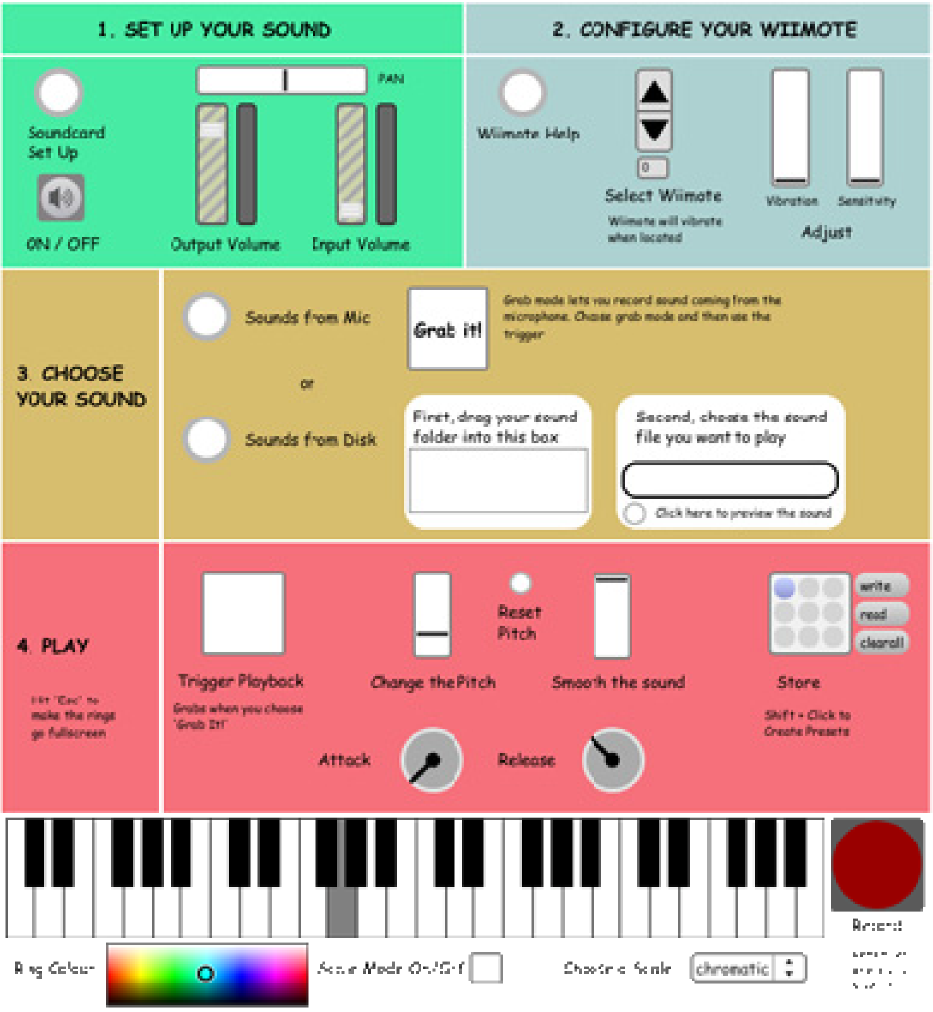

Figure 4. *The Graphical User Interface, designed in consultation with information designer Myah Chun.*

6. CONCLUSION

This system has been used in number of collaborative workshops and performances at the South Bank Centre, London, and at the Frank Barnes School for the Deaf, Camden, London. Some of these sessions featured members of the London Philharmonic Orchestra working with disabled students from Whitefields school. These events were documented by the Sonic Arts Network, and the BBC. In addition, several compositions were directed by Duncan Chapman. The system has been improved to allow ease of use for both hearing and non-hearing players of varying ability so that they may collaborate in performance in ways that are immediate and inherently musical. Beyond this, the system has shown genuine potential for use as a therapeutic tool.

The software was made publicly available free of charge in 2008 by the Sonic Arts Network. In addition, some source code will be released as part of the AHRC funded project, Cognitive and Structural Approaches to Contemporary Computer Aided Audiovisual Composition. This project was demonstrated as part of a BBC technology article, due for publication in Summer 2008.

Acknowledgements: The staff and students of Whitefields School for the disabled, London.

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Using immersion in a musical virtual space environment to enhance quality of body movement in young adults with hemiparesis

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ABSTRACT

This paper focuses on the application of musical virtual space environments in the rehabilitation of individuals with motor disabilities. It is contended that the use of such environments has the potential of enhancing performance through engagement of the person in meaningful and functional activities. Our study describes and evaluates the use of a musical virtual space to increase the quality of movement and improve gross motor functioning in four young adults with hemiparesis. Results showed that immersion episodes in the musical virtual environment provided highly engaging experiences that fostered body movement and social interaction. After twenty immersive sessions, participants revealed gains in the aesthetic quality of gestures performed in dancing responses to music. There were also significant improvements regarding gross motor functions, namely in parameters such as stability, coordination, flow, effort, and mobility.

1. INTRODUCTION

Traditional rehabilitation practices focuses on treatment of specific impaired skills thought to underlie the functional limitations of people with disabilities. This perspective builds on an *interventionist-centred* model that regards disabled persons as in need of services from a professional who can provide specialized therapy to address impairments caused by given dysfunctions. Focused on the achievement of discrete goals and outcomes, *interventionist-centred* practices provide an organizing structure for interpersonal processes in which the therapist becomes the sole controlling agent of action. Such orientation does not factor in or take advantage of the preferences for activities that clients might want to do, or to avoid. While ignoring these aspects, the *interventionist-centred* model disregards the importance of personal choices, concerns, appeals, likes and dislikes of the individuals whose disabilities are being addressed in therapy programs (e.g., Rosenbaum et al., 1998).

During the past few years, views on rehabilitation have been moving from an *interventionist-centred* framework to a *whole person* approach, which emphasises the therapeutic significance of engaging disabled people in meaningful and functional activities (Williams, 2001). One of the fundamental premises underlying such perspective is that individuals are more likely to participate in activities in which they are interested and in which they elaborate on existing assets (Dunst, 2004). When truly involved in an activity, they have opportunities to practice current abilities and use their often-residual capabilities to acquire new skills. Individuals may try out new possibilities, exploring and finding out how their behaviours can make things happen. In this way, they have the chance to learn about their own abilities, strengthening their sense of mastery (Raab & Dunst, 2006).

Two types of interest are likely to influence individuals' engagement in activities: *personal interests* and *situational interests* (Renninger, 2000). Personal interests are specific to individuals and involve their knowledge of positive feelings about an experience or activity. On the other hand, situational interests refer to enjoyment evoked by the appealing quality of situations or contexts. Thus, a situational interest emerges when the characteristics of an activity or event draw the individual's attention and curiosity, inviting him or

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her to become involved. Conditions that have ingredients of novelty, surprise, and exploration can originate situational interests (Krapp et al., 1992).

Musicological aspects of human functioning have been historically neglected in comparison with other capabilities revealed by members of our species. Yet, musicality – an attribute that encompasses aspects such as sensitivity for music, expression of music skills, or predispositions for processing and enjoying musical experiences – might have evolved even before speech in the human evolutionary process (Papoušek, 1996). Related to the inherited architecture of the mind, human musicality has universal presence across age, sex, or cultures, and fosters a strong intrinsic motivation for its manifestation. Therefore, it is not surprising that activities associated with music tend to evoke both personal and situational interests.

Our study lies on the assumption that musical virtual spaces are valuable contexts for promoting engagement in action. The concept of musical virtual space refers to an environment where human physical movements are translated into real time auditory feedback provided through appropriated stimuli for music-making (e.g., percussive sounds, notes from different scales, and chords delivered by distinct "instruments"). While interacting with such environments, immediate "musical" responses to gestures are likely to be so pleasing that make individuals unaware of the effort involved in the generation of movement (Brooks, et al., 2002). Pleasurable experiences resulting from immersion in musical virtual spaces increase the motivation to move and stimulate the performance of motor activities. On the other hand, if embedded in meaningful interpersonal contexts, movements produced in relation with technology may acquire a communicative value, developing into expressive gestures. These gestures, taken as social valued bodily expressions, are likely to be analysed through their creative aesthetical sense.

The aim of the present paper was to explore the use of a musical virtual space environment as a therapeutic tool in the rehabilitation of individuals with hemiparesis. Participants were invited to take part in a "dancing workshop" where they were free to explore the sonic effects of their movements within a musical virtual space. During the "workshop" sessions, the facilitator stimulated them to develop themes using expressive "dance" movements as a way to avoid a potential sterile "technology-led" approach. Since the fundamental principle of the intervention was to engage participants in meaningful dance-related activities, assessment outcomes were primarily focused on improvements regarding the aesthetic quality of gestures produced in response to music. Although the intervention was not explicitly designed to treat or correct their specific impairments, we expected that promoting participants engagement in "dancing" activities would induce some positive changes in impaired functions. Therefore, typical aspects of gross motor functioning were also addressed in the assessment procedures.

2. METHOD

2.1 Participants

Participants were four young adults (2 males and 2 females) with congenital hemiparesis associated with intellectual and language impairments. Their ages ranged from 19 to 25 years old and they were all attending full-time rehabilitation services in an occupational unit for persons with severe disabilities. Inclusion criteria included moderate to less than mild difficulties in changing body positions (from sitting down to standing up or lying down), walking, jumping, moving both upper and lower limbs, understanding verbal instructions, and perceiving contingencies between one's own gestures and the delivered auditory feedback. Furthemore, participants had no significant visual or hearing impairments. Their legal carers signed the informed consent.

2.2 The Musical Virtual Space

The musical virtual space environment was created using Soundbeam 2™. This device was chosen because it can be operated by anyone without musical skills and with minimal motor capabilities.

Applying a movement tracking technology, Soundbeam emits ultrasonic invisible beams inaudible to human ears. The emitted pulses activate sensors so that any physical movement performed in the range of a beam, generates data, which are immediately translated by digital systems into auditory signals. Moving a limb in space can result in the sound of a harp, an ensemble of voices, or bells for example. Although it is possible to incorporate visual components, in our study only sonic feedback responses were programmed.

Each participant's tracked gesture controlled the pitch variation of a MIDI instrument. Several modes were selected with different sorts of variables: (1) the number of generated notes, (2) the relationships between those notes – i.e., scales, chords, and arpeggios – (3) the required articulation for activate the notes – i.e., movement dynamics in relation to the sensor –, and (4) secondary information pertaining aspects such as velocity, pitch-bend, and depth modulation. The choice of program was left as an option in the interface, as well as the possibility of shifting or lowering the register of each instrument. Four sensors were attached to the MIDI, creating a three-dimensional playing space of around nine squared meters where "players" had the opportunity to move expansively. Each sensor was positioned in a specific angle so that beams could adequately "capture" participants' movements generated by their upper or lower parts of the body.

2.3 Procedure and Measures

The four young adults agreed to participate in a 3-month "dancing workshop". During the first three sessions, they were presented with two kinds of music pieces: one symphonic (excerpts from the "Dance of the Swans" of Tchaikovsky's Swan Lake) and the other disco-sound type ("Come on Eileen" performed by the Dexys Midnight Runners & Kevin Rowland). Both pieces had acoustic resemblances with the sound templates used within the musical virtual space. Each participant was then invited to hear those pieces and to "dance" freely in response to the music. Their performance was videotaped in order to be analysed as pre-test data.

Four sensors were attached to the MIDI, creating a three-dimensional playing space of around nine squared meters where "players" had the opportunity to move expansively. Each sensor was positioned in a specific angle so that beams could adequately "capture" participants' movements generated by their upper or lower parts of the body.

After these first sessions, participants were introduced in the musical virtual space environment. These sessions took place three times a week and lasted approximately one hour and a half. Participants were all present and seated in face of the virtual space. During the initial immersion experiences, they were invited to explore individually the environment. With time and following the indications of the facilitator, they were encouraged to elaborate musical patterns. They were also stimulated to develop narrative themes using expressive "dance" movements to generate sounds, which should be congruent with the feelings or ideas that they were trying to convey. After some sessions, group activities were introduced with the intent of exploring new sonic effects and "composing musical themes" together. Experiences of immersion in the musical virtual space environment involved a total of twenty sessions and they were all video recorded.

For evaluation purposes, the same pre-test procedures were adopted in three additional sessions, following immersion experiences. "Dancing" activities during these last sessions were video recorded in order to be analysed as post-test data.

Fourteen samples of each participant were randomly extracted, at the pre and post-test sessions (seven for the pre-test and seven for the post-test). The time length of the video samples ranged from three to four minutes. In each sample, the aesthetical quality of the dancing gestures was rated with a global score by a professional dancer using a coding scheme with several parameters mentioned in Table 1 (full descriptions and rating procedures are available from the fourth author). Ratings for each participant ranged from 0 to 5 points.

Table 1. *Parameters used to assess the quality of the dancing movements*

PARAMETERS
Improvisation
Elements of movement
Spatial relationships
Mass movement
Harmony
Themes
Choreographic intent

In order to assess gross motor functions, the same video samples were rated using five scales adapted from the *Video Documentation of Motor Behavior* – VDMB (Camargo et al., 1998). Scales are succinctly described in Table 2 (full definitions are available from the third author) and ratings extended from 1 to 6 points.

Hence, for each participant, pre and post-test measures comprehended a total of fourteen scores regarding the aesthetic dimension, and a sum of seventy scores concerning gross motor functions (fourteen ratings in five scales), corresponding to a full amount of eighty four scores.

Table 2. *Description of the rating scales used in the assessment of gross motor functions*

CATEGORIES	SUMMARY DESCRIPTION
Stability	Maintains trunk control and balance while in gross motor activity, such that there is no evidence of transient propping or loss of balance that affects performance
Coordination	Uses two or more body parts together while performing moving activities such as walking, shaking…
Flow	Uses smooth and fluid arm and hand movements when performing activities that involve the use of upper limbs
Effort	Regulate or grades the speed and extend of movement while performing moving activities
Mobility	Actively flexes, rotates or twists the trunk in manner and direction appropriate to the moving activity

Participants' involvement during immersion sessions in the musical virtual space was assessed through the Engagement Assessment Scale – EAS – (Lopes-dos-Santos & Nanim, 2008). The EAS is an assessment tool specifically designed to evaluate levels of engagement in activity settings where individuals are invited to express themselves with movement or body postures in reaction to music. Scores are assigned considering that engagement behaviour results from a conjunction of responses implying attention, interest, enjoyment, and action. According to the EAS rating system, levels of engagement are scored in a range of 1 (nonengaged) to 7 (very intensively engaged) points. Likewise, a scale specifically designed for the current study evaluated social behaviours in the same immersion sessions. This scale focuses on positive social behaviour that indicates participants' willingness to engage in social interactions while performing within the musical virtual space environment. It considers behaviours that occur between peers, but not those that may take place between participants and the facilitator. For assessment purposes, a distinction was made between situations where participants were acting alone or performing in-group. Therefore, each participant could have two separate ratings within the same session. Participants' behaviours were rated within time sampling intervals of three minutes each. Since, during the same session, a participant was likely to be observed across several time sampling intervals, means were computed to obtain an overall rating of his or her behaviour throughout the session. According to the coding scheme (available from the first author), rates could vary between 1 point (no interaction) and 7 points (very active and persistent in social interactions).

2.4 Data Analysis

Due to the small sample size, results are presented for each participant. Whenever possible, scores were analysed employing non-parametric statistics. Rather than aiming inferential purposes, the use of these statistics intended to provide a basis for a better appreciation of individual data trends.

3. RESULTS

3.1 Engagement and Social Behaviours in Immersion Sessions

Figure 1 presents medians of engagement behaviour ratings for each subject in the first seven and the last seven immersion sessions.

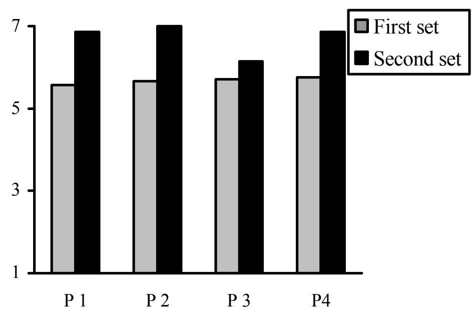

Figure 1. *Medians of engagement behaviour ratings for each participant in the seven first and the seven last immersion sessions.*

There was a general increase of social behaviours across the sessions. The fact that group activities were more frequent during the last sessions may explain this finding. However, watching the videos it seemed that the quantity of social interchanges tended to grow (laughs, verbal comments, etc.) even when participants were individually performing in front of their peers within the musical virtual space environment. Thus, we compared for each subject ratings of social behaviour in the first seven sessions with ratings in the last seven sessions.

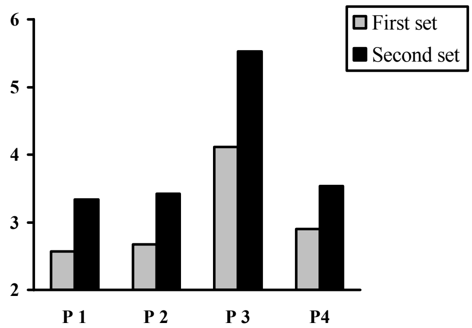

Figure 2. *Medians of social behaviour ratings in the seven first and in the seven last immersion sessions for each participant while they were individually performing within the musical virtual space environment.*

Figure 2 shows the obtained medians in the two observation sets. These results, suggest that the amount of social interchanges grew from the first to the second set. The one-tailed Wilcoxon Signed Ranks Test (with alpha defined at .10) indicated that increases were significant for participant 1 (Z = -2.04; $p<.04$), participant 2 (Z = -1.65; $p<.10$), and participant 3 (Z = -2.41; $p<.04$). Regarding participant 4 the difference was not statistically significant (Z = -0.74; $p>.29$).

3.2 Aesthetical Quality of the Dancing Performance Before and After Immersion Sessions

Ratings of the aesthetical quality of dancing were assigned to each participant in seven video samples from the pre-test sessions and in other matched seven samples from the post-test sessions. Medians are presented in Figure 3.

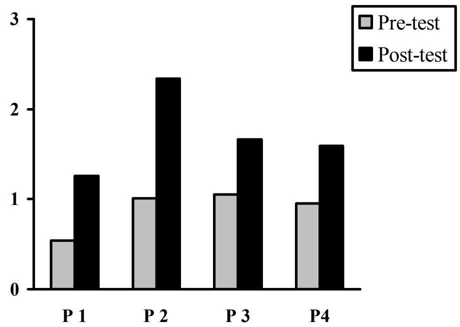

Figure 3. *Median scores assigned to the quality of dancing performances of each participant at the pre and the post-test.*

The one-tailed Wilcoxon Signed Ranks Test showed that difference between the pre-test and the post test ratings were significant for participant 1 (Z = -2.37; $p<.01$), participant 2 (Z = -2.36; $p<.01$), participant 3 (Z = -2.36; $p<.01$), and participant 4 (Z = -2.36; $p<.01$).

3.3 Gross Motor Functions Assessed Before and After Immersion Sessions

During the so-called pre-test and post-test sessions, five gross motor function parameters were assessed through using video records of participants' dancing activities. We extract several samples (of 3/4 minutes) for each subject at the pre and post-test phases. These samples were divided in two main groups according to the type of music that was being played. Concerning the pre-test, three samples of disco sound music and four samples of symphonic music were randomly chosen for each participant. Regarding the post-test phase, we followed the same procedure. Thus, the seven pre-test samples were matched to the seven post-test samples in relation to the type of music.

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Figure 4 presents, for each participant, the medians of the scores assigned to the five gross motor parameters at the pre and at the post-test assessments.

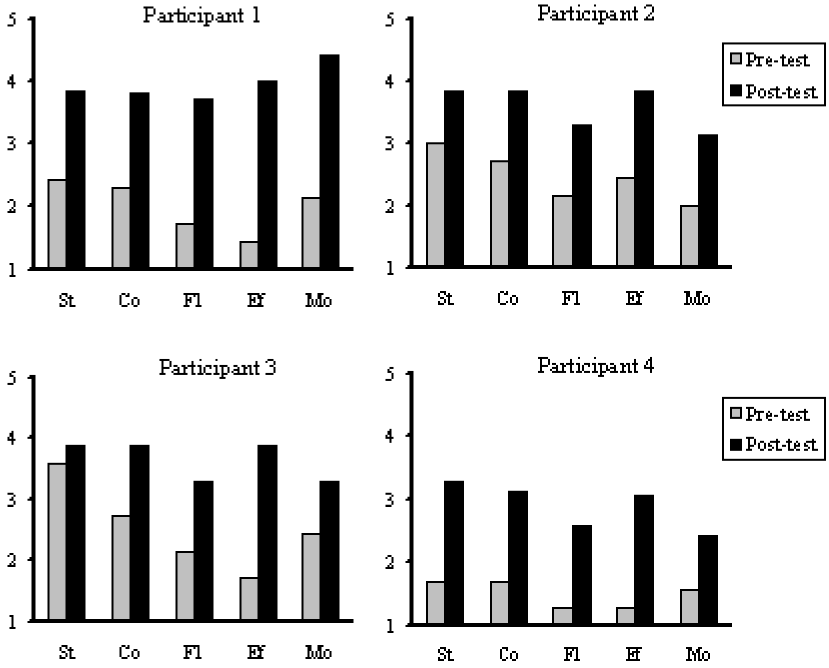

Figure 1. *Median scores assigned to Stability (St), Coordination (Co), Flow (Fl), Effort (Ef), and Mobility (Mo) for each participant at the pre-test and the post-test sessions.*

Graphic representations suggest that there was a general increase of motor gross performance after participants' experiences within the musical virtual space environment. One-tailed Wilcoxon Signed Ranks Test results (pre-test *versus* post-test) for each subject are presented in Table 3.

Table 3. *Results of the Wilcoxon Signed Ranks Test (pre-test versus post-test) with indication of p values.*

	Stability	Coordination	Flow	Effort	Mobility
Participant 1	Z = -2.27; p<.02	Z = -2.41; p<.01	Z = -2.23; p<.02	Z = -2.39; p<.01	Z = -2.46; p<.01
Participant 2	Z = -2.12; p<.03	Z = -1.84; p<.07	Z = -1.99; p<.04	Z = -2.42; p<.01	Z = -2.06; p<.04
Participant 3	Z = -1.00; p>.31	Z = -2.07; p<.04	Z = -1.63; p<.10	Z = -2.39; p<.01	Z = -2.12; p<.04
Participant 4	Z = -2.43; p<.01	Z = -2.27; p<.02	Z = -2.26; p<.02	Z = -2.20; p<.02	Z = -2.12; p<.04

With alpha value set at .10, differences were all statistically significant except for participant 3 whose stability scores did not show important gains between the pre and the post-test.

4. DISCUSSION

The conceptual basis for providing intervention services to persons with disabilities has significantly evolved during the past few years. Indeed, contemporary views on rehabilitation shifted from an *interventionist-centred* orientation to a *whole person* approach in which therapy plans are designed to provide opportunities for interest-based involvement in meaningful and functional activities. Such involvement is likely to promote engagement and to encourage the practice of existing abilities. As individuals use their current assets to participate in activities, they are able to build upon them new skills and capabilities (Browder, 2001).

Assuming that music-related activities tend to elicit both personal and situational interests, the present study immersed four young adults with hemiparesis in a musical virtual space. Results showed that immersion experiences were highly engaging. As reported, participants revealed a remarkable persistence in interacting with the acoustic virtual space, exploring its potentialities for extended lengths of time. This finding is consistent with the assertion that individuals' interests are more likely to be evoked by situations or environments in which elements of novelty, surprise, and exploration are prevalent (Krapp, et al., 1992).

Social interchanges between participants increased across the immersion sessions. Such circumstance is seen as a direct consequence of the progressive introduction of group "tasks" in the performed activities. However, the increasing number of social interactions could be documented even when participants were acting alone in front of their peers. With time, the interactive "solitary play" with sounds gave place to frequent displays of behavioural patterns in which the willingness to receive social feedback was quite evident. Smiles, laughs, verbal comments, gazing exchanges became gradually more frequent and were particularly likely to occur when performed actions produced interesting sound feedback responses. This growing tendency to incorporate activities in the context of interpersonal processes probably reflects the effects of practice and learning. It was obvious that participants acquired a progressive capacity to interact creatively within the musical virtual space. Since social behaviour is fuelled by feelings of efficacy following self-recognized achievement of mastery (Shonkoff & Philips, 2000), the enhanced sense of control might have encouraged involvement in social interactions.

Comparing "dancing" performances at the pre and at the post-intervention sessions, our findings suggest that immersion experiences in the musical virtual space environment increased participants' sense of aesthetical awareness. Actually, results documented significant gains regarding the expressive dimension of movements produced in response to music.

On the other side, assessments of gross motor functions revealed net improvements in aspects such as balance, fluency, amplitude of gesture, and coordination of both upper and lower limbs. Concerning this last observation, it is important to stress that our intervention was not specifically focused on impairments. However, the fact of engaging participants in dance-related activities brought up functional benefits. It is likely that movements required by performance of "dancing" activities have instigated improvements in underlying motor functions.

A fundamental premise of the *whole person* approach is that rehabilitation practices should concentrate on enhancing activities that involve a broad range of competencies. Individuals with disabilities have fewer opportunities to take part in common life experiences (Simeonsson, McMillen, and Huntington, 2002). Such restrictions are likely to reduce their capacity to learn from physical and social environments and to operate as disability-amplifying factors. Research studies document, for example, how specific neuromotor disorders may be the starting point for the development of disablement processes that affect several other domains of human functioning (Bruyère, et al., 2005).

Although further research is needed, our findings support the hypothesis that musical virtual space environments can have the potential to address multiple skills within the same activity. On the other hand, previous studies conducted in the context of the *Soundbeam Project* suggest that experiences with the "invisible, elastic keyboard in space" provide important foundations for fostering development of abilities pertaining domains such as attention, imagination, mastery motivation, self-reliance, spatial orientation, motor planning, memory, reflective cognition, language, and social-skills (e.g., Ellis, 1997; Russell, 1996). Therefore, the use of musical virtual space environments may be a valuable therapeutic tool in intervention practices inspired by conceptual assumptions of the *whole person* approach.

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Mix-it-yourself with a brain-computer music interface

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ABSTRACT

This paper is a follow up from the work presented at the ICDVRAT 2006 conference in Esbjerg, where the first author introduced a Brain-Computer Music Interface (BCMI) to control a generative music system. Here we introduce a new musical application for the BCMI (an EEG-controlled music mixer) and report on efforts to make our BCMI system cheaper to implement, more portable and easier for users to operate. We also comment on a new method that we are developing to generate melodies from the topological behaviour of the EEG.

1. INTRODUCTION

Despite advances in technology, opportunities for active participation in music making are limited for people with differentiated physical and mental abilities, especially those with severe complex disability. At present, access music tutors use gesture devices and adapted accessible technology to make this possible, which achieve great results in most cases. For people with severe physical disabilities, however, having the ability to interact with the environment created for them by the facilitator can sometimes be difficult. This prevents them from engaging in the many emerging community initiatives, which may provide opportunities for recreational music-making including performance, composition and creative workshops. A brain-computer interface for music recreation and therapy could be the only option for many with disability to have a musical voice and thus benefit from more active participation in recreational and therapeutic music opportunities.

At the ICDVRAT 2006 conference in Esbjerg, the first author introduced a proof-of-concept Brain-Computer Music Interface (BCMI) to control a generative music system (Miranda 2006). The BCMI was programmed to look for information in the EEG signal and matched the findings with assigned generative musical processes corresponding to different musical styles. It activated generative rules for two different styles of piano music (e.g., Satie-like and Beethoven-like), depending on whether the EEG indicated salient low-frequency or high-frequency components in the spectrum of the EEG. Every time it had to produce a bar of music, it checked the power spectrum of the EEG at that moment and activated the generative rules accordingly. Subjects were able to lean to control the EEG in order to voluntarily produce high power in the low- or high-frequency bands of the EEG's spectrum. Therefore, they were able to actively steer the system to generate Satie-like or Beethoven-like of music. Because at the time we were more interested in implementing an experimental proof-of-concept system, we did not consider issues concerning the usage of the system in real-world applications. The system comprised expensive EEG equipment, three computers and a myriad of different software, some of which were not entirely compatible with each other, and had to be hacked.

In this paper we introduce a new musical application for the BCMI: an EEG-controlled music mixer. We also report on continuing efforts to make the BCMI system cheaper to produce, more portable, more stable and easier for users to operate. Finally, we briefly introduce a new technique that we are developing to produce music from the topological behaviour of the EEG signal.

2. TECHNICAL BACKGROUND

Human brainwaves were first measured in the early 1920s by Hans Berger. He termed these measured brain electrical signals the electroencephalogram (literally "brain electricity writing"). Berger first published his

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brainwave results in an article entitled "*Über das Elektrenkephalogramm des Menschen*" (*On the Electroencephalogram of Man*) (Berger 1929). The English translation would not appear until the end of the 1960s (Berger 1969). He had a lifelong obsession with finding scientific proof of a causal linkage between the psychical world of human consciousness and the physiological world of neurological electrical signals.

The EEG is measured as the voltage difference between two or more electrodes on the surface of the scalp, one of which is taken as a reference. The standard convention for placing electrodes on the scalp uses electrodes placed at positions that are measured at 10% and 20% of the head circumference (Figure 1). The terminology for referring to the position of the electrodes uses a key letter that indicates a region on the scalp and a number: F = frontal, Fp = frontopolar, C = central, T = temporal, P = parietal, O = occipital and A = auricular (the ear lobe; not shown in Figure 1). Odd numbers are for electrodes on the left side of the head and even numbers are for those on the right side. The set of electrodes being recorded at one time is called a montage.

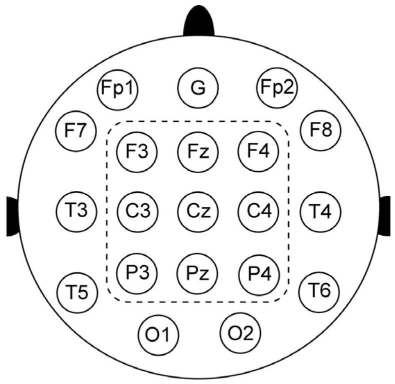

Figure 1. *The EEG is detected with electrodes placed on the scalp at positions measured at 10% and 20% of the head circumference. The terminology for referring to the position of the electrodes uses a key letter that indicates a region on the scalp and a number.*

The EEG expresses the overall activity of millions of neurons in the brain in terms of charge movement, but the electrodes can detect this only in the most superficial regions of the cerebral cortex (Misulis 1997). Today, the EEG has become one of the most useful tools in the diagnosis of epilepsy and other neurological disorders. Further, the fact that a machine can read signals from the brain has sparked the imaginations of scientists, artists and other enthusiasts, and EEG has made its way into a myriad of other applications.

A brain-computer interface uses information extracted from the EEG to control devices, such as a wheelchair or a computer cursor (Dornhege et al. 2007). Although most current efforts into BCI research focus on EEG, other techniques for measuring brain activity have been attempted; for example, near-infrared spectroscopy and magnetoencephalography (MEG). In the case of the EEG, it takes many thousands of underlying neurons, activated together, to generate signals that can be detected. The amplitude of the signal strongly depends on how synchronous is the activity of the underlying neurons. The EEG is a difficult signal to deal with. It is filtered by the meninges (the membranes that separate the cortex from the skull), the skull and the scalp. There are a number of approaches to EEG analysis, such as power spectrum, spectral centroid, Hjorth, event-related potential (ERP), principal component analysis (PCI) and correlation, to cite but a few (Niedermeyer and da Silva 1987). Although powerful mathematical tools for analysing the EEG already exist, we still lack a good understanding of their analytical semantics in relation to musical cognition.

In the work presented in this paper we have used power spectrum analysis. Power spectrum analysis is derived from techniques of Fourier analysis, such as the Discrete Fourier Transform (DFT). In short, DFT analysis breaks the EEG signal into different frequency bands and reveals the distribution of power between them. This is useful because the distribution of power in the spectrum of the EEG can reflect certain brain states. For example, spectra with salient low-frequency components are known to be associated with a state of drowsiness, whereas spectra with salient high-frequency components are normally associated with a state of alertness. There are five recognised frequency bands of EEG activity, also referred to as EEG rhythms, each of which is associated with specific brain states referred to as delta, theta, alpha, low beta and high beta rhythms. They certainly indicate different brain states, but there is, however, some controversy as to the exact boundaries of these bands and the states with which they are associated. It is often said in the literature that alpha rhythms (conveyed by frequency components ranging from 8Hz to 13Hz) indicate inattention and relaxed, almost drowsy, state of mind. The beta rhythms (conveyed by frequencies ranging from 13Hz to about 40Hz or so) seem to indicate active thinking, active attention and solving concrete problems (e.g., calculations, planning).

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3. THE BCMI MIXER

The BCMI mixer system controls the faders of a music mixer. For instance, assume a piece of music recorded into 3 tracks: the first track contains the beat, which has a constant rhythm (bass and drums). The second and the third tracks main contain piano and guitar solos, respectively. Instead of activating generative rules for two different styles of music (as we have done previously), here we use the activity of the EEG to control the faders for the second and third tracks: the power (or amplitude) of the beta rhythms controls the fader for track 2 and the power of the alpha rhythms controls the fader for track 3 (Figure 2). Therefore, if the system detects prominent alpha rhythms in the EEG, then the guitar solo sounds louder. Conversely, if the system detects prominent beta rhythms, then the piano solo sounds louder.

In contrast to our previous system which comprised expensive 32-channel EEG medical equipment, three computers and hacked software, the BCMI mixer runs on a single personal computer and uses an affordable 4-channel EEG amplifier manufactured by MindPeak, USA (Figure 3). Although the accuracy of the latter lags behind the accuracy of our previous EEG amplifier, we believe that it is satisfactory enough for recreational, and even therapeutic, purposes. Moreover, the BCMI controls an off-the-shelf relatively easy to use music production software (Reason, manufacturer by Propelerhead, Sweden), which makes the whole system much more user-friendly to operate and customise.

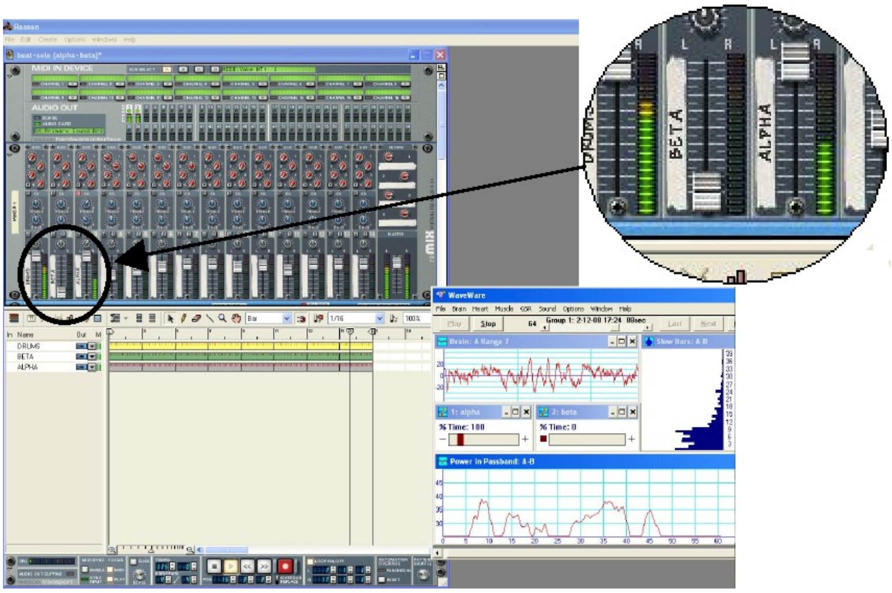

Figure 2. *The BCMI music mixer controls the faders of the mixer of a music production program called Reason, manufactured by Propellerhead, Sweden.*

Figure 3. *The BCMI mixer system uses an ordinary PC, affordable EEG equipment with serial or USB connection and off-the-shelf software, making it user-friendly and easy to operate.*

4. TOWARDS MORE SOPHISTICATION

We are currently experimenting with a new method to generate music with the EEG, which requires more sophistication with respect to the analysis of the signal and understanding of its meaning.

Besides the information conveyed by the overall activity of different frequency bands, the EEG signal certainly conveys a number of other types of information, which might be significant for music control. We are currently looking at the topological behaviour of the EEG as it varies across different regions of the cortex. Instead of analysing the overall EEG resulting from the summation of the signals from all electrodes simultaneously, we consider the signal of each individual electrode separately. Figure 4 plots an extract of the individual signals from 14 different electrodes organised as shown in Table 1.

Table 1. *The montage of 14 electrodes used in our experiments.*

Electrode number	Electrode name as shown in Figure 1
1	Fp1
2	Fp2
3	F7
4	F5
5	F4
6	F8
7	T3
8	T4
9	T5
10	P3
11	P4
12	T6
13	O1
14	O2

We extract information from the signals of each electrode in order to infer possible trajectories of specific types of information across the montage. For instance, in Figure 5 we demonstrate how the power of the signals shown in Figure 4 has varied on the scalp in 5 steps. The area with the highest EEG power moved from electrode 2 (Fp2) to 1 (Fp1), then 5 (F4) and then 6 (F8), where it remained for two steps. The length of the window used to analyse the power of signals defines the number of steps. (The length of the window is arbitrary.)

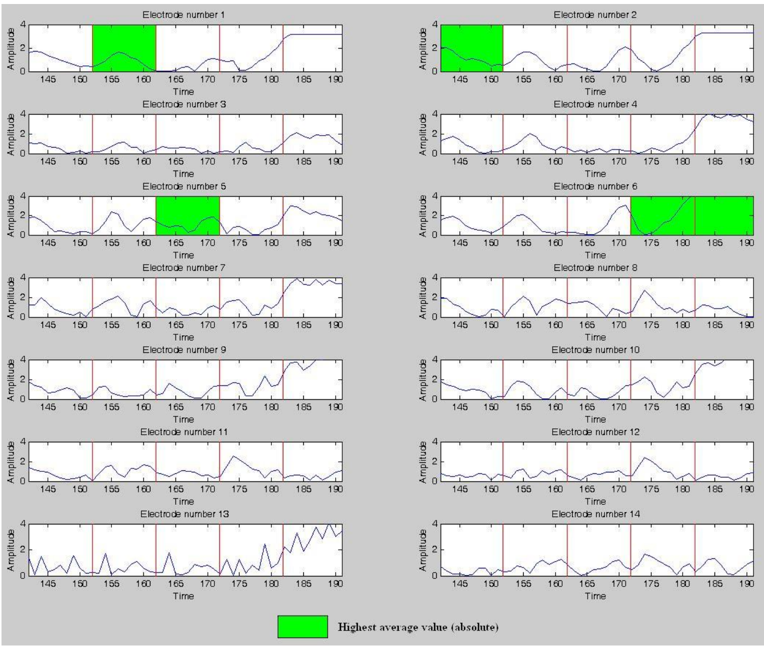

Figure 4. *An extract of the individual raw EEG signals of 14 electrodes.*

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A number of analyses could be performed here. For instance, one could analyse the trajectory of alpha rhythms (Figures 7 and Figure 5 on the right) or beta rhythms (or both simultaneously), correlation between electrodes or sets of them, synchronisation between one or more electrodes, and so on (Giannitrapani 1985). Much research is needed to establish the meaning of the trajectories in terms of cognition or state of mind, particularly with respect to music cognition.

Table 2. *Associations between musical notes and the electrodes of a given montage.*

Electrode number	Electrode name as shown in Figure 1	Musical note
1	Fp1	A4
2	Fp2	A4#
3	F7	B4
4	F5	C5
5	F4	C5#
6	F8	D5
7	T3	D5#
8	T4	E5
9	T5	F5
10	P3	F5#
11	P4	G5
12	T6	G5#
13	O1	A6
14	O2	A6#

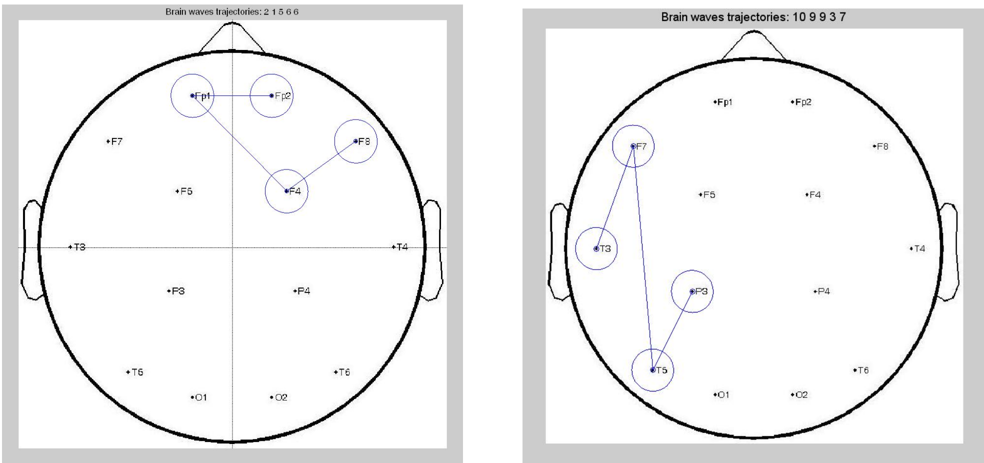

Figure 5. *(Left) The trajectory of EEG power information on the scalp in 5 steps. (Right) The trajectory of alpha rhythm information on the scalp in 5 steps.*

We have developed a simple but nevertheless effective method to generate melodies from the trajectories of the type illustrate in Figure 5 on the left. Each electrode is associated with a musical note (Table 2), which is played when the respective electrode is the most active with respect to the EEG information in question. In the case of this example, the information is the power of the raw EEG signal. The associations between notes and electrodes are of course arbitrary. Considering the associations in Table 2, the trajectory shown in Figure 5 on the left would have generated the melody shown in Figure 6.

5. CONCLUSION

We tested the BCMI mixer on the same person (a member of our research team) who was trained to control our previous BCMI for generative music. After a few minutes, the colleague was able to control the mixer at his own will.

As the system is more portable and more user-friendly to operate than its predecessor was, we plan to take it out of the lab to be tested in real-world scenarios. One problem that we may encounter is that the EEG of a person with differentiated physical and mental abilities might behave differently. We need to provide straightforward means for calibrating of the system to cope with differentiated EEG signals.

Figure 6. *Generated melody from trajectory shown in Figure 5.*

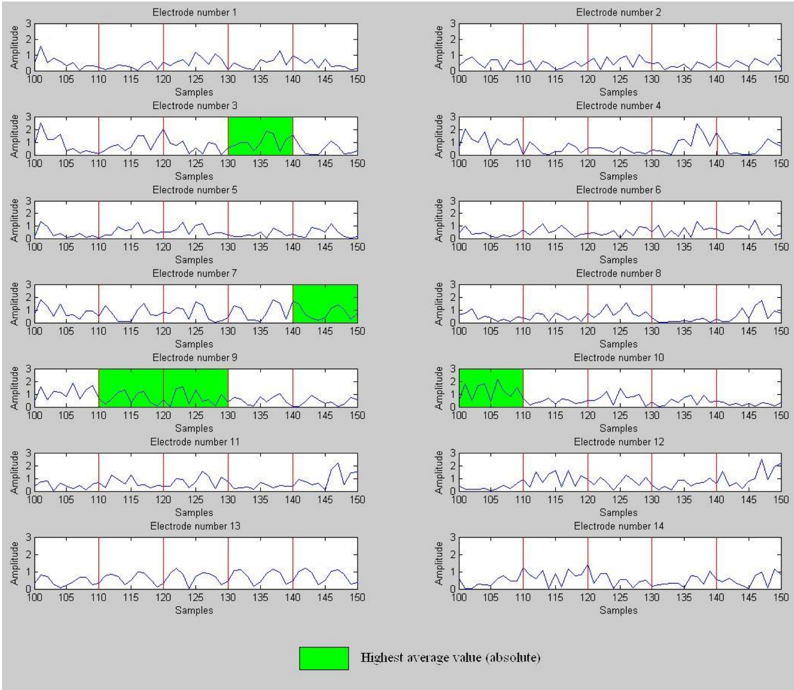

Figure 7. *An extract of the individual EEG analysis of 14 electrodes showing alpha rhythms.*

Although we have demonstrated that it is possible to produce inexpensive BCMI systems using off-the-shelf hardware and software, we acknowledge that there is a limit as to how far you can go with such approach to engineering and design. Because the EEG signal needs much amplification, the amplifiers and associated electronics need to be of the highest quality possible, and this comes at a price. It may not be possible to produce solutions like the one we proposed for the BCMI mixer, as we move towards more sophistication. For example, our new method for generating melody from the topological behaviour of the EEG necessarily requires a reasonably large number of EEG channels and bespoke software.

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